MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CXXV.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

LONDON:
Published by the Institution,
GREAT GEORGE STREET, WESTMINSTER, S.W.
[TELEGRAMS, "INSTITUTION, LONDON." TELEPHONE, "3051."]
1896.

ADVERTISEMENT.

The Institution as a body is not responsible either for the statements made, or for the opinions expressed, in the following pages.

NOTICE.

To insure the punctual delivery of the Minutes of Proceedings, and of other communications from the Institution, it is essential that every change of address should be notified without delay to—

THE SECRETARY,
THE INSTITUTION OF CIVIL ENGINEERS,
Great George Street, Westminster, S.W.

LONDON: PRINTED BY WM. CLOWES AND SONS, LIMITED, STAMFORD STREET AND CHARING CROSS.

CONTENTS.

SECT. I.—MINUTES OF PROCEEDINGS.

3 and 10 *March*, 1896.

17 *March*, 1896.

24 *March*, 1896.

31 *March*, 1896.

SECT. II.—OTHER SELECTED PAPERS.

SECT. III.—ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1895-96.—PART III.

Sect. I.—MINUTES OF PROCEEDINGS.

3 March, 1896.

WILLIAM HENRY PREECE, C.B., F.R.S., Vice-President, in the Chair.

It was announced that the several Associate Members hereunder mentioned had been transferred to the class of

Member.

James Burnett.
Joseph Percival Clarke.
William Dawson (*Bangor*).
William Dawson (*Leyton*).
Reginald Eaton Ellis.
Charles Firth.
Charles Henry Holme.
William Sewell.
Frederick Sharp.
Wilhelm Westhofen.

And that the following Candidates had been admitted as

Students.

Joshua Edward Ackfield.
Robert Bawn Addis.
Samuel Percy Andrews.
Robert Fleming Arnott, B.E.
Walter Henry Bell.
Arthur Oldfield Cautley.
Alexis Armand Dallison Charles.
Hugh Stanley Cheshire.
James William Cross.
Gerard Finch Dawson.
Alexander Wannan Donaldson.
Charles Beresford Fox.
Edwin Percy Harvey, B.A.
Francis Cecil Hounsfield.
Frederick Arthur Hurley.
Arthur Henry Jones.
Douglas Stanley Malden.
William Middleton.
Henry Kellett Oakes.
William Thomas Redford.
John Keith Ross, M.A., B.Sc.
Charles Edward Shackle.
Frederick Gerard Sheffield.
Fulwar Estoteville Skipwith.
Charles Edmund Joseph Smith.
Charles Ernest Spiking.
James Douglas Stuart.
Thomas Julian Tolmé.
Norman Stewart Paget Trimingham.
John Burdett Willis.

The Candidates balloted for and duly elected were: as

Members.

John Ernest Etlinger.
Charles Otto Gleim.
William Metcalf.
William Patterson Orchard, B.E.

Associate Members.

GORDON ALLEN.
ADAM SEDGWICK BARNARD.
DAVID LEONARD BARNES.
HARRY FREDERICK CAREW-GIBSON.
RAYMOND HOWARD EMTAGE, Stud. Inst. C.E.
HENRY KEITH FORBES, Stud. Inst. C.E.
ARTHUR LIVESEY FORRESTER, Stud. Inst. C.E.
JOSEPH HETHERINGTON.
CHARLES RICHARD JUDD.
JAMES MCDOUGALL, B.A.
GEORGE NAPIER.
LESLIE RADCLYFFE.
JOHN HALL RIDER.
JOHN SUTCLIFFE.
FELIX ALEXANDER TARGET.
THOMAS TIMMINS.
WILLIAM REGINALD WADE.
WILLIAM DONALD WILSON WHITE.
BERNARD RUSSELL WILLS, B.A., Stud. Inst. C.E.

(*Paper No. 2934.*)

"Littoral Drift: in its relation to the Outfalls of Rivers, and to the Construction and Maintenance of Harbours on Sandy Coasts."

By WILLIAM HENRY WHEELER, M. Inst. C.E.

IN the design of works for the improvement of entrances to tidal rivers, or in the construction of harbours on coasts encumbered with sand or shingle, one of the most important elements for consideration is the movement of the littoral drift.[1] Its effect in the formation of bars has already been dealt with by the Author in a Paper[2] read before the Institution in 1890; and some existing shingle beaches, and the direction of movement of drift round the coast, as well as the historical and geological conditions relating thereto, have formed the subjects of Papers by the late Sir John Coode,[3] Professor Sir Joseph Prestwich,[4] Mr. Redman,[5] and Mr. Pickwell.[6] It is intended to deal in the present Paper only with coast erosion, and the travel of material as affecting engineering works carried out on the coasts for the benefit of navigation.

In the Paper[3] presented by Sir John Coode and the discussion upon it, a law was deduced from the facts observed at the Chesil Bank as to the direction in which drift moved, and as to the governing agent in its movement, which has since been generally accepted as correct. Further observations, however, and new facts which have since become available, appear to the Author to demand a

[1] See "Principles and Practice of Harbour Construction," by W. Shield, p. 71.
[2] Minutes of Proceedings Inst. C.E., vol. c. p. 116.
[3] *Ibid*, vol. xii. p. 520.
[4] *Ibid*, vol. xl. p. 61.
[5] *Ibid*, vol. xi. p. 162, and vol. xxiii. p. 186.
[6] *Ibid*, vol. li. p. 191.

modification of the conclusions then arrived at. The conditions under which the channels of rivers, and the approaches to harbours on sandy coasts can be maintained, have also undergone material alteration during recent years. The successful application of the system of suction dredging to the removal of sand, and the working of these machines in positions and under circumstances which formerly would have been considered impracticable, has placed at the disposal of engineers new and important facilities for carrying out works of improvement.

The propositions which the Author desires to establish are—

1. That the vast deposits of sand and shingle in bays and sheltered places on the coast, are due to causes which occurred in remote ages, and which are no longer in operation.

2. That the drift which travels along a coast is due to the erosion of the cliffs, and is derived from the wasting of the land, and not from the sea-bed.

3. That the quantity of drift is limited, so that it may be entirely stopped or its movement controlled.

4. That while wind and waves are the agents which operate in eroding the cliffs and producing the drift, the regular and continuous travel of the material along the coast is due to the wave-action of the flood-tide.

5. That the regular and continuous movement of sand and shingle along a coast takes place only in the zone lying between low- and high-water mark.

6. That the contour of the sea-bed on a sandy coast, when covered with a moderate depth of water, remains in a stable condition, and that so long as the conditions remain the same the form of the banks and depth of the channels are not altered by winds and waves.

7. That channels can be effectively deepened and maintained on sandy coasts by dredging; and, if properly directed, they will remain stable and retain their depth.

8. That harbours may be projected out from sandy coasts without danger of the entrances shoaling, provided that the piers are so placed as to derange the main set of the tidal current as little as possible, and are carried into a sufficient depth of water, and that, where required, the supply of littoral drift is cut off by protective works along the coast.

In dealing with the question of littoral drift and the accumulation of sand and shingle, sufficient consideration does not appear to have been given to the vast time that has been occupied in their production, and to the fact that the amount now to be dealt with

is comparatively small. There are no forces in operation that could, within any conceivable period, produce the great mass of sand which overlies the rocky bed of the sea round many parts of the coast, and the accumulations which exist in sheltered estuaries, or the large shingle beds such as the Chesil Bank, which extends for 15 miles with a base 600 feet wide, its top reaching between 20 and 40 feet above high water and extending as far below low-water level. These deposits must have accumulated at a time when the agents at work were of much greater magnitude than now, and when the tides rose higher and occurred at more frequent intervals. These sandbanks, although still slowly growing in some cases, have probably not been materially altered in form since the end of the glacial period; when the torrents arising from the melting of glaciers and icebergs assisted in moulding the shape now assumed by the rivers and estuaries, and the shoals and deeps of the sea-bed along the coast.

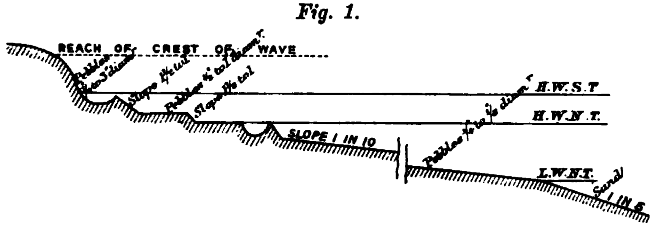
The Source of Littoral Drift.

The material which is drifted along the coast consists of shingle, sand and alluvial matter. It is derived from the erosion of the cliffs, the degradation of which is more or less rapid, depending on whether they consist of the primitive rocks, or of those which have been at some time degraded, and redeposited. Waves are the principal agents of destruction, by the beating of which on the cliffs at high water in gales and storms, large masses of rock are dislodged, the fragments thus broken off being used as battering rams in further work of disintegration. Incessantly rolled about by the waves, the disintegrated rock becomes ground to boulders, then to shingle, and finally to sand. When the cliffs are of chalk or of clay, the flints, gravel, and boulders supply the shingle and sand; while the remainder is converted into alluvium, the particles of which are sufficiently fine to become mixed with the water and remain in suspension so long as the water is in motion. The degradation of cliffs is further aided by rain and frost; and, where the drainage is imperfect, landslips constantly occur and cause the wasting away of land bordering on the sea. The material thus eroded from the cliffs and broken up, is continually in motion under the influence of the waves and tides, travelling along the coast in a direction determined by causes to be described. The power of waves to move material in heavy storms breaking on the shore is almost beyond comprehension. Stones weighing between 200 and 300 lbs., are rolled along and left

stranded on the beach; and pebbles of great size are thrown to a height considerably above the level of high water. At Brighton it is recorded that, in south-west gales, the shingle has been thrown on to the road 18 feet above high-water level; and shingle banks are frequently found between 8 and 10 feet above high-water level. During a single gale, 3¾ million tons of shingle were moved along the Chesil Bank, the greater part of which was thrown back within a few days; and in a subsequent gale, 4½ million tons were scoured out, three-fourths of which was moved back within five days. It has been calculated that at Hove 2,700 tons were removed from the beach during one set of spring tides.

Shingle.—The pebbles sorted from other material eroded from the cliffs become heaped in a bank, the base of which is almost invariably above low-water level. Shingle is rarely found below low-water mark; and the regular travel of both shingle and sand along a coast is confined to the zone lying above low water of neap tides.

Fig. 1.



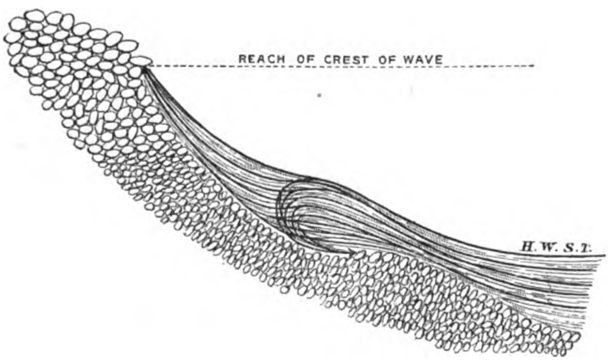
There are exceptional cases, as at the Chesil Bank, where the shingle extends below low-water level;[1] and isolated patches of shingle are to be found in deep water, but these are stationary and have no connection with the ordinary littoral drift. A remarkable instance of the fact that shingle travels in a direction marginal and adjacent to the shore, is afforded by a fact recorded by Mr. Ellice-Clark, that a quantity of shingle, amounting to about 25,000 tons dredged from Shoreham Harbour, and deposited on the beach in front of Hove, at distances varying between 400 and 800 yards from the sea-wall, was moved up the beach, and deposited along the foot of the sea-wall by the action of the sea.

The material drifted along the coast is sorted by the wave-action, the largest pebbles being driven up nearly to the top of the bank, the size gradually decreasing till the pebbles merge into sand as the low-water level is approached. The summit of a

[1] Minutes of Proceedings Inst. C.E., vol. xii. p. 522.

shingle bank is nearly always above the level of high water of spring tides, generally between 4 and 8 feet, the height depending on the force of the waves which break on the banks. In calm weather the face of the banks becomes heaped up, assuming what is termed a full, or ridge, and hollow parallel with the coast, *Fig. 1.* The slope of the face in the upper layers, in calm weather, is sometimes as much as 1 to 1. In stormy weather it is drawn down to a slope of between 7 to 1, and 10 to 1. The slope of the lower part of the bank is much flatter, or about 30 to 1. The wave, on striking the bank, divides into two parts, the crest running up its face and carrying with it the pebbles, and at the same time pushing forward those that lie above it, *Fig. 2.* The pebbles, on being moved, are actuated by the momentum of the wedge-shaped mass of water, into which the

Fig. 2.



crest of the wave has been resolved, and they are almost entirely waterborne. The advancing wave strikes the bank obliquely, and has the greatest effect when this angle is about 45°. The water returns down the line of quickest descent, or normal to the bank, and carries down with it a portion of the pebbles; but in the case of the upper layer, which is subject only to the thin end of the wedge of water, there is not sufficient depth to affect them, and consequently they remain stranded. Each successive wave acting in an oblique direction, pushes the stones a certain distance forward along the face of the bank; one wave of each series, usually the tenth, rising higher and acting with more force than the others. This process for ever acting is sufficient to account for the removal of an immense amount of material. The lower part of the wave, on striking the bank, curls round and cuts out a hollow in the

face of the bank in the manner shown in *Fig. 2.* Two such hollows will almost invariably be found in all shingle banks, one at the level of the spring tide, and the other at that of the neap tide, and a third also frequently at the level of an extraordinarily high tide. In heavy gales the under-tow of the waves removes a large quantity of pebbles downwards, and flattens the slope of the bank.

The travelling shingle generally follows the coast-line, moving round the arcs of bays, and indents, and round projecting points where the water is shallow; and the back of the bank is connected with the shore. Occasionally the bank assumes the form of a ridge extending along the chord of the indent, being thus isolated from the shore; sometimes also it extends across the mouth of a river, either diverting its course, or blocking its outfall. The most notable instance is afforded by the Chesil Bank, which extends as a ridge for several miles, having on its inside a large sheet of water, receiving the discharge from several streams which at one time emptied directly into the sea. The limit of this bank has been reached, and it has long ceased to advance. Another instance is to be found on the east coast, where a shingle bank, still travelling southwards, has diverted the river Alde out of its course for 9 miles. The river flows on one side of the bank and the sea on the other, being separated by the shingle, which in places is only 70 or 80 yards in width. In the estuary of the Ribble, a shingle ridge, between 10 and 12 feet wide on the top, projects from the land near St. Anne's for $\frac{3}{4}$ mile. In Felixstowe Bay, the shingle runs in a bank across the hollow of the bay, parallel with the low-water line, leaving a considerable space between it and the cliff. In other cases the travel of the shingle has been arrested by some natural or artificial projection; and it has collected in vast beds, as at Dungeness, Pevensey, Languard Fort, and Folkestone.

Sand.—This material consists of minute angular particles derived from the fragments eroded from the cliffs, and which are free from all earthy matter, and so do not discolour the water. Particles of pure sand, owing to their size, only remain in suspension in the water when much agitated, and they rapidly settle as soon as motion ceases. The bed of the sea, round all except rocky coasts, consists principally of sand ranging between a thin covering of the rocks and beds of immense thickness. Sand lies much flatter than shingle, the slope varying between about 1 in 100 and 1 in 300. In exceptional cases, sand beaches have a very steep slope, the face lying at an angle of $1\frac{1}{2}$ to 1 or 2 to 1; and

frequently, when submerged and subject to strong tidal currents, they stand much steeper than the natural angle of repose. Waves breaking on a beach stir up the sand and throw it temporarily into suspension. While in this condition, it is carried along by the flood-tide until brought into contact with some obstruction, when, in the slack water thus caused, the sand settles and accumulates. This deposit is greatest at the point reached by high water of spring tides, and tails down towards low water, and in the direction from which the drifting action proceeds.

Under ordinary conditions the movement of sand takes place only between low and high water, during the time the waves of the flood-tide break on the beach. In stormy weather, with on-shore winds, when the waves break below low-water mark, sand is disturbed and thrown into suspension, and in this condition may be thrown up on to the beach, and accumulated in large masses against any projection from the coast. But the depression thus made in the sea is rapidly filled again, and the general contour of the beach is restored in calm weather.

Silt and Alluvium.—Silt consists of sand mixed with a varying quantity of clay, chalk, or other alluvial matter which gives a certain adhesiveness to the particles, depending in amount on the larger proportion of the alluvial matter. Alluvium found in the sea along coasts, is derived from the erosion and wasting of cliffs composed of chalk or geological deposits of recent formation, and material brought down by rivers. Although the specific gravity of the alluvium is as high as that of sand, yet, owing to the minute size of the individual particles, it is more easily kept in suspension in the water, and becomes diffused by tidal action throughout a very large area. Oscillating backwards and forwards with the tides, the alluvium gradually subsides to the bed of the ocean during periods of calm weather. Beds of alluvial matter are thus found in the sea-bed near the outfalls of all large rivers, but generally in the deeper part of the ocean. Thus in the Bay of Biscay, off the mouths of the Loire and Gironde, there are beds of soft mud, 20 miles in breadth, which extend for about 150 miles; and in the English Channel and North Sea, off the coast of Flanders and the mouth of the Thames, there are also large beds of alluvial matter. Pure alluvial matter is not, therefore, drifted along tidal coasts; but occasionally in sheltered places some portion of it settles on the coast, and, gradually accreting in time, forms the salt marshes to be found in many estuaries. In stormy weather, with heavy on-shore gales, the alluvial matter settled on the

beach is disturbed, and, becoming diffused by the action of the waves, discolours the water for several miles out from the coast, and is carried by the tides into estuaries. Such occasions, however, are exceptional. Thus, off the mouth of the Scheldt, in the pass of Wielingen, where there is a large deposit of alluvial matter, in heavy gales from the north-west, the water becomes so turbid as to cover everything with which it comes in contact with mud, and vessels passing through it require to be scrubbed. On more than one occasion within the experience of the Author, during very heavy gales from the north-east, the whole of the water in the offing along the Lincolnshire coast, from the Humber to the Wash, has been rendered muddy, and the tide flowing up the rivers has left a deposit behind. A similar effect is produced on other parts of the coast; and occasionally, during north-easterly gales, the tidal water enters Harwich Harbour in a turbid condition. It does not, however, penetrate far, and no deposit is left behind, the ebb-current carrying it out to sea again. These occasions are, however, rare; and, as a rule, sea-water along a tidal coast is bright and clear.

It is held by some geologists and engineers that the wasting of the clay cliffs of the Yorkshire coast, north of the Humber, supplies the alluvial matter to be found in that river, and "that it seriously affects the navigation of the river, and is the cause of enormous expense in dredging at the Grimsby and Hull docks."[1] The amount of alluvial matter in suspension in the Ouse and the Trent, the two rivers which unite to constitute the Humber, is perhaps larger than that contained in any other river in England. The deposit on land adjacent to these rivers prepared for warping is at the rate of between 2 and 3 inches in a tide. This is quite sufficient to account for the amount of material that has to be dredged out of the docks. It is impossible that this material can be supplied by the sea. The only current along this coast is that due to the tides, which may be taken as running at the rate of 2½ knots. The material thrown down on the beach from the clay cliffs by the waves at high water is not reached till after half-flood, so that the flood, or southern current, only acts on it for about three hours, and cannot transport such of it as is taken up in suspension for a greater distance than 7½ miles. It then becomes subject to the ebb-current which lasts upwards of six hours and carries the suspended material 15 miles northwards, the net result being that each tide leaves the

[1] Minutes of Proceedings Inst. C.E., vol. li. p. 210.

material $7\frac{1}{2}$ miles further north than the point from which it started. With every movement of the tide the suspended matter becomes diffused over a wider area, and ultimately settles in the bed of the sea. If any of it ultimately should reach the mouth of the Humber, it would be in such an attenuated quantity as to be imperceptible. On the flood-tide, the water in the Humber is bright and clear for a distance of between 7 and 10 miles above Spurn Point; when heavy freshets are running, the water is discoloured on the ebb for about 4 miles outside Spurn Point. The Author has taken samples of the water at various parts of the Humber, from its mouth in the North Sea upwards into the Ouse and Trent, and has found the water at the mouth, on an inflowing tide, bright and clear and containing only a few grains of sand, the quantity of material in suspension increasing with the progress up the river. The water in the Trent at 6 miles from its mouth was, on the first of the flood, exceedingly turbid; and the quantity of matter in suspension amounted to 3,150 grains per cubic foot, and at Gainsborough to 261·87 grains.

It is contrary to all known laws of tidal action in rivers for material to be carried upwards from the sea to any great distance above their mouths. The tidal wave creates only an oscillating current, the same volume of water which moves up the river moving down again on the ebb. Matter in suspension moves upwards under the influence of the tidal current only a certain distance, depending on the duration and velocity of the current, seldom exceeding 10 miles, but never to the full extent of propagation; on the turn of the tide, if it remains in suspension, it is moved back again the same distance by tidal action, and a further distance due to the downward motion of the fresh-water current, depending in amount on the relative volume of the fresh to the tidal water. If there be no fresh water, the downward movement is only equal to the upward movement. Further, the salt from the sea which is more readily diffused than material held in suspension, only penetrates the lower reaches of a tidal river, the water entirely losing its saline properties as the tidal wave progresses upwards. The water in the Ouse and the Trent is free from salt, the specific gravity of that in Goole docks being 1·00, and in the North Sea 1·026. The action of tidal water in transporting material in suspension in rivers has been fully demonstrated by an elaborate series of experiments with floats, and by ascertaining the amount of salt in the water of the Thames, and also on the Clyde, the Witham, and the Scheldt, the

details of which are given in the Author's treatise on Tidal Rivers.[1] It is necessary to draw particular attention to this matter, as it has frequently been held that deposits in rivers and estuaries are due to material brought in from the sea by the flood-tide. Thus the late Sir John Rennie, in the scheme for the reclamation of part of the Wash, which obtained parliamentary sanction in 1851, based his calculation as to the accretion of the land to a great extent on material brought into the estuary from the degradation of the Yorkshire coast. The scheme has been frequently revived in recent years as a means of finding work for the unemployed. The engineers who advised the carrying out of the Norfolk estuary scheme for enclosing 30,000 acres on the north side of the Wash, in like manner calculated that the supply of alluvium brought in from the sea was unlimited. A study of the physical condition of the transport of littoral alluvial drift would have shown the impossibility of this, and thus have saved a large outlay on a practically abortive scheme.

The theory that alluvial matter is brought in from the sea is also advanced in the Memoir of the Geological Survey of the County of Lincoln. A careful examination of the tidal water flowing into and out of the estuary of the Wash from the open sea shows that no such inward drift of alluvial matter takes place. The water of the flood-tide, except during occasional heavy on-shore gales, as it enters the estuary, is bright and clear; and it only becomes turbid as it approaches the upper end of the estuary, and meets the water flowing down the rivers charged with alluvial matter.

The condition of Harwich Harbour, situated lower down on the same coast, affords an example in refutation of the theory that alluvial matter, wasted from adjacent cliffs, is carried by the sea into harbours or up rivers. Until preventive measures were taken, the cliffs extending for some miles north of Harwich Harbour, Fig. 3, Plate 1, consisting of London clay, were being rapidly eroded and worn away by the action of the sea. The drift along this coast is from north-east to south-west, and shingle is carried along the coast and drifted into the harbour; but no alluvial matter, except under the conditions above mentioned, finds its way into it, or becomes deposited on its bed, or on the shores of the rivers Stour and Orwell. These rivers drain only a comparatively small area compared with the size of the rivers and the harbour, and bring down very little alluvial matter, such

[1] "Tidal Rivers, their Hydraulics, Improvement, and Navigation," by W. H. Wheeler, chap. vi.

quantity as is brought down being carried out to sea on the ebb-tide. The water, both in the harbour and rivers, is bright and clear; and no dredging has been necessary to maintain the original depth in Ipswich dock, which has been constructed upwards of fifty years.

The Mersey also contains a large amount of alluvial matter in suspension, which it has been held is washed in from the sea. The Author has taken samples of the water carried in over the bar on the flood-tide, and has found it bright and clear, having only a few grains of sand in suspension. It only becomes turbid as it approaches Liverpool and meets the downward current charged with material derived from the erosion of the cliffs in the upper estuary, and the alluvium and detritus brought down by the rivers.

The Severn, the Usk, and the Parret afford other examples of rivers having a large amount of matter in suspension; but that this is due to alluvial matter brought down these rivers by freshets, and not to material transported from the sea, is evident from the fact that while the water is excessively turbid in the upper reaches, it is bright and clear on the flood-tide in the lower end of the Bristol Channel, turbid water never being met with lower than Lynton. The alluvial matter in these rivers oscillates backwards and forwards with the tide, varying in quantity and position with the amount of fresh water flowing down, the turbid zone being situated lowest when heavy freshets prevail.

Dover Harbour affords another example that the transport and deposit of alluvial matter are due to local sources, and that it is not derived from the sea. Before the construction of the Admiralty Pier, the deposit in Dover Harbour amounted to upwards of 60,000 tons a year, which had to be moved by dredging, in order to maintain a sufficient depth of water.[1] This material consisted principally of chalk and sand derived from the wasting of the cliffs. As the Admiralty Pier extended into deep water, the deposit became less, and finally ceased. The tidal water ebbing in and out, now being derived directly from the sea, with a depth of between 6 and 7 fathoms, instead of from the shallow current running along the shore, enters clear and free from matter in suspension. At Ramsgate where the depth at the entrance is not more than between 1 and 1½ fathom, about the same as it was formerly at Dover Harbour, and where the water is derived from the shore current, the amount of material continually deposited is very great.

---

[1] Evidence of Mr. E. Druce, Dover Harbour Report, 1875.

Quantity of Drift Limited.

The quantity of littoral drift to be encountered in dealing with rivers and harbour works on sandy coasts, may be so large as to be uncontrollable, or may only be such as to be capable of removal by dredging at a reasonable cost for maintenance. If the material is not only supplied by the erosion of the coasts, but is also due to sand or alluvial matter thrown up from the bed of the sea, the supply in such case is unlimited and uncontrollable. There is, however, nothing to warrant any such conclusion. If sand is continually cast up from the bed of the sea by the waves, the beach would be steep, and not flat as generally found; and all bays, estuaries, and indents along the coast would have been filled many ages ago. It is found, however, that the beach is denuded during on-shore gales, and grows during those blowing off shore; bays and indents being kept open by the under-tow of the waves, which, when driven into them, create a strong back current which tends to denude the beach, and keeps the bay from accreting. If the movement of sand and shingle along a coast, be arrested by groynes, or other projections, and the supply thus cut off, the beach beyond soon becomes denuded and lowered, showing that the supply of drift is a limited quantity and therefore within control. If also forces were now in operation which could create the great accumulations to be found on some parts of the coast, the task of coping with them would be hopeless, but such is not the case. In Morecambe Bay, the sand-beds cover an area of 90,000 acres dry at low water, and in the Duddon estuary they cover 9,000 acres. It is impossible that this enormous mass of material can ever have been supplied by any forces now in operation. The rivers which discharge their contents into these estuaries are comparatively small streams, and quite incapable of performing such a task; and there is no wasting away of the coast-line at all comparable to the formation of these sand-beds.

The Wash, Fig. 4, Plate 1, covers an area of about 157,600 acres, of which about 84,000 acres consist of sand-beds dry at low-water, the average thickness of which may be taken at 20 feet. The Author has at various times, and under various conditions, analysed the water flowing down the rivers which empty into this estuary, and ascertained that the quantity of matter brought down in suspension is only sufficient to provide material for the growth of the salt marshes which have accreted along the coast, and that it is physically impossible for these sand-beds to have been

produced by detritus brought down the rivers under their present condition.

On the north coast of France, the erosion of the cliffs along the Calvados coast is estimated by French engineers to take place at the rate of about 0·90 foot a year, or a quantity equal to 25,000 cubic yards per mile. A great part of this is alluvial matter which becomes diffused amongst the tidal water, and settles in the bed of the English Channel. It has been estimated by Mr. de Lamblardie[1] that the proportion of silex derived from the erosion of the chalk cliffs of the coast of Normandy is three-fifths of the whole, and that the remainder is alluvial matter capable of being carried in suspension. Allowing that one-half of the material produced is sand and shingle, and supposing that its travel was arrested by groynes and accumulated at the foot of the cliffs all along the 36 miles of the shore, over the zone of shallow water which extends for a width of $1\frac{1}{2}$ mile, it would have caused an average deposit of about $\frac{1}{24}$ inch a year; and about 1,500 years would be required for the beach to be raised an average height of 6 feet.

There is a bank extending from the shore at the entrance of the Seine, opposite Trouville, on which the water shoals at 2 fathoms. Allowing that this bank was formed by the littoral drift derived from the waste along 45 miles of the coast of Calvados, and that one-half of the deposit derived from the eroded matter had been deposited there, the time occupied in the operation would have been about 9,000 years. The quantity of shingle drifted along the coast past Dieppe has been estimated as varying between 30,000 and 40,000 cubic yards a year. Even if the whole of this had to be dredged to secure the maintenance of the port, the annual cost would be insignificant compared to the traffic; but that the whole of it might be arrested and prevented from reaching the port is evidenced by the fact that the removal of this material for concrete and ballast had a sensible effect on the supply, and greatly relieved the port from accumulation;[2] and the erection of groynes on the west shore further stopped the movement. On the coast of Normandy, where the waste of the chalk cliffs is as great or even greater than along the Calvados coast, the supply of shingle drifting along the shore is so limited that, owing to its being used to ballast vessels, the beach became so denuded that special works had to be constructed to protect the coast. The

[1] "Étude sur les Rivières à Marée et sur les Estuaires," by H. L. Partiot. Paris, 1892, p. 97.

[2] "Harbours and Docks," by L. F. Vernon-Harcourt, p. 147.

same result occurred at Spurn Point at the entrance to the Humber. The clay cliffs between Bridlington and that river extend over a length of about 40 miles, the average height being about 40 feet, and the mean annual waste 6·60 feet,[1] representing a quantity equal to 2,072,160 cubic yards. The shingle from this erosion travelled southwards along the beach to Spurn Point, where it accumulated. The removal, however, of 30,000 cubic yards a year of shingle for road-mending and concrete so denuded the beach at Spurn Point as to threaten its safety. This appears to indicate that about one-seventh only of the eroded material produced shingle, the remainder being alluvial matter and sand. The taking of the shingle was stopped, and the beach again accumulated and the erosion of the cliffs diminished one-half. If the whole of this eroded material had been spread out on the beach between high- and low-water marks, which may be taken as extending over a width of one-fifth of a mile, the beach would have been raised annually 3 inches, and in seventy-two years the shingle bank would have been above the level of high water, and the supply of material from the erosion of the cliffs entirely stopped.

When the pier was projected from the shore of the English Channel at Folkestone, the shingle travelling along the beach from the west was arrested and accumulated in a large bank; but the beach at Dover and eastward of it became in consequence denuded, and the safety of the cliffs was considerably endangered. The supply from the west has also been materially affected by the projection of Dungeness Point, which has acted as a natural groyne arresting the travel of shingle brought from the coast west of this point.[2] The amount collected here in thirty-five years was found to be 430 acres, 7½ feet deep, representing 7,000,000 tons, or at the rate of 200,000 tons a year. The result of this has been to limit materially the supply travelling eastward of this point.

Between Beachy Head and Dungeness, a distance of 20 miles, the average height of the cliff may be taken as 200 feet. At the rate of 0·90 foot a year, the quantity eroded would be about 1,000,000 tons. The proportion of alluvial matter would then be four-fifths, the remaining fifth being the quantity of shingle annually deposited at Dungeness. The shingle deposit at Dungeness covers an area of nearly 6,000 acres, the surface being between 4 and 6 feet above high water, and the thickness of the shingle

[1] Minutes of Proceedings Inst. C.E., vol. li. p. 211.

[2] See Report by Sir John Coode included in "Correspondence relative to the causes of the wasting of the shore to the eastward of the Government Pier at Dover." Return to an Order of the House of Commons, 13 March, 1873.

bed being estimated at 22 feet. If this shingle is derived from the wasting of the cliffs between this point and Beachy Head, it represents the accumulation of 1,662 years.

At Felixstowe, Fig. 3, Plate 1, a natural groyne, composed of septaria, projected from the cliffs and held up the shingle to the north of it. On the removal of this stone, about thirty years ago, for cement-making, the shingle at once began to travel southwards, and the sea encroached on the cliffs. To prevent this, considerable expense has had to be incurred in constructing groynes to arrest the travel of the shingle and consequent wasting of the beach. The shingle set at liberty began to travel across Harwich Harbour, forming a spit nearly ½ mile long. To prevent this, a large groyne was constructed extending a considerable distance from the coast at Languard Point, and this arrested the travel, the shingle accumulating at the back of the groyne. The result of the stoppage of the travel has been that the shoaling across the harbour has ceased, and the beach inside has become so denuded as to cause the wasting away of the land, threatening destruction to the fort. To prevent this, part of the groyne has been removed and a portion of the shingle allowed to escape, the inner beach being protected with groynes.

Transporting Agency.

Attention was first directed to the moving agent of shingle in a Paper presented by Mr. Palmer in 1834 to the Royal Society,[1] in which he divided the action into three classes: (1) Heaping up or accumulating; (2) disturbance or breaking down; and (3) progressive movement; and contended that all of these were due to the effect of wind, and that tidal action alone was not capable of effecting the result produced. Sir John Coode, in his Paper[2] on the Chesil Bank, adopted the view that the progressive action of littoral drift is due to, and moves in the direction of, the prevailing winds, and "that the ultimate movement of shingle is always found to be in the same direction as, and never against, the heaviest seas; and that it is frequently in opposition to the prevailing or strongest tidal current." This view has since been generally accepted. Prof. J. Prestwich,[3] in a subsequent Paper, expressed agreement with the conclusions arrived at by Sir John Coode, "that the

[1] "Observations on the Motion of Shingle Beaches," H. R. Palmer. Philosophical Transactions of the Royal Society, April 1834.

[2] Minutes of Proceedings Inst. C.E., vol. xii. p. 532.

[3] *Ibid*, vol. xl. p. 63.

shingle is propelled along the coast by the action of wind-waves, and the heavy seas due to the prevailing and strongest winds," in which opinion the majority of the speakers who took part in the discussion again concurred. Sir James N. Douglass, however, differed, and expressed the opinion that "the travel of shingle along the coasts was due to the effect of the ocean-wave or ground swell."[1] Other writers attribute the effect not to the "prevailing" but to the "dominant" winds, or those which blow on shore with the greatest force and in the direction of the flood-tide; the prevailing winds being regarded as those which blow with the greatest frequency from one particular quarter. Mr. Vernon-Harcourt[2] ascribes the progressive movement of littoral drift to the combined action of the winds and the tidal currents, and considers that the action is most powerful when the waves and tides act in the same direction; the tidal action being only due to the difference in force of the flood and ebb. Mr. Shield, in his recent work on harbours, remarks "that the direction of littoral drift is in the great majority of cases determined almost solely by that of the prevailing winds."

The prevailing winds in England are from the south-west, the wind blowing from this quarter for about two-thirds of the year; and some of the heaviest gales also come from this direction. If the movement of littoral drift is due to this cause, it must be in the same direction all round the coast, whereas on the south coast the general direction is easterly, on the west coast northerly, and on the east coast southerly. On the north coast of France, Belgium, and Holland, where the prevailing winds are also south-westerly, the drift travels in several directions, but principally to the east and north. On the west coast of France and Spain the prevailing winds are from the north-west,[3] the general direction of travel of the drift being opposite to this and northwards with the flood-tide. In the Gulf of Gascony, the tides produce littoral currents which travel up the coast from south to north with the flood-tide; and the sand travels along the coast from the south, and proceeds north to the point of Négade, and then north-easterly to the mouth of the Gironde following the set of the flood-tide.

On the American coast from Sandy Hook to Cape May, along the sea-coast and in the inlets and bays, the prevailing wind being

---

[1] Minutes of Proceedings Inst. C.E., vol. xl. p. 103.
[2] Harbours and Docks, p. 62.
[3] Admiralty Sailing Directions, Coast of France.

north-easterly, the beach travels in some cases north and in others south, these directions corresponding with the set of the flood-tide along the shore.[1]

On the south coast of England, the material travels round Lyme Bay[2] with the flood-tide, in a direction varying from north-east to south-east; along the south-east coast, from Bognor to Beachy Head, the general direction of the drift is almost due east; from Beachy Head to Dover it is north-east; from Dover to the North Foreland northerly; from the North Foreland to the mouth of the Thames westerly; and north of the Thames south-westerly. Over such a limited area the "prevailing wind" can only blow from one direction. On the east coast north of Harwich Harbour, the shingle travels south-easterly; and, until preventive measures were taken, part of it was gradually extending in a long bank or spit across the harbour (shown by dotted lines, Fig. 3, Plate 1), the remainder rounding Languard Point and travelling along the beach in a north-easterly direction, in both cases working with the flood-tide. Further up the east coast, north of the Wash, the travel is south-eastwards; south of the Wash, along the coast of Norfolk, there is a large shingle bank the travel of which is eastwards; while in the Wash is another travelling southwards, in each case following the set of the flood-tide. The long shingle bank at Aldborough, 9 miles in length, travels south-west with the set of the flood-tide. On the west coast, north of the Ribble estuary, the travel of the shingle past South Shore and Blackpool is northwards, up the Ribble estuary past St. Anne's and Lytham the travel is eastwards, in each case in the direction of the flood-tide, the prevailing and dominant winds being south-west.

In the Bay of Bengal, where the monsoon blows continually for several months, there are two movements of the sand in opposite directions. During the north-east monsoon, the movement is from north to south, in the same direction as the wind; but as soon as the north-east monsoon ceases, the direction is reversed, and the drift moves in the opposite direction with the set of the flood-tide. In the north of the Arabian Sea the drift is south-east, the flood-tide setting from the north-west, the monsoon which blows from the south-west for a time arresting the progress of the material.[3]

On the east coast of Africa, although the Mozambique current

---

[1] "Littoral Movement on the New Jersey Coast," Lewis M. Haupt. Transactions of the American Society of Civil Engineers, vol. xxiii. pp. 123 and 148.

[2] "Tidal Rivers," by W. H. Wheeler, p. 162.

[3] Minutes of Proceedings Inst. C.E., vol. xliii. p. 4.

passes along the coast from north to south, the sand travels from south to north, in the same direction as the set of the flood-tide.[1]

The general effect of the wind on the travel of drift is as follows: Gales blowing obliquely on-shore, in the same direction as the flood-tide, cause the waves to rise higher, and they are then the most active agents in eroding the cliffs and providing and transporting material. Strong direct on-shore gales denude and cut out material that has been deposited, and lower the beach. In off-shore winds and calm weather the material accumulates and raises the beach. Winds blowing continually from one quarter, in an opposite direction to the ordinary travel of the drift, will have the effect of causing the waves to strike the beach at a different angle to that caused by the tidal waves, and reverse the direction of movement. Under such circumstances, shingle or sand may become deposited across the entrance to a river or harbour mouth and block the entrance for a time. This effect ceases when the gale abates; and the movement of the material resumes its normal direction.

With regard to the effect of the tidal current alone in moving material, the velocity of this current along a coast in the open sea is seldom more than 2 to 2½ knots, and never sufficient to move pebbles and stones of the size found in shingle beaches; and, as the flood and ebb last the same time, if the movement were due to the tidal currents it would be of an oscillating character, the sand or shingle being moved backwards and forwards within a certain zone. On shores where the rise and fall of the tide and the direction of the current are not coincident, as is frequently the case in narrow seas, the current outside the range of the waves breaking on-shore will move floating material in one direction, while the wave-action of the on-shore tide is moving the shingle in the opposite direction. Further, the current alone cannot have the effect of heaping up shingle at a height considerably above the level of the highest spring tides.

A careful examination of the movement of littoral drift, on several different parts of the coast in this and other countries, shows that the continuous progressive movement is invariably in the direction of the flood-tide. The Author has not been able to find a single instance in which the regular and continuous movement of littoral drift is in an opposite direction to that of the flood-tide. During long-continued gales, blowing in an opposite direction to the flood-tide, the normal condition may be arrested for a time, yet as

[1] Minutes of Proceedings Inst. C.E., vol. cxviii. p. 86.

soon as this cause is removed the travel again assumes its natural course.

The continuous progressive movement of sand and shingle along the sea-coast is due then, not to winds or tidal currents, but to the wave-action of the flood-tide, this action being increased when the height of the waves is increased by the wind blowing in the same direction as the flood-tide. The action of the flood-tide making along a coast does not consist in a gradual swelling or raising of the water, but a series of small waves are given off from the main tidal wave, which break on the shore in an oblique direction. Even on the calmest days these breaking waves have sufficient force to roll the material of which the beach is composed upward and onward in the direction in which the tide is making. The constant murmur that is heard on a shingle beach even on a calm day, rising to a roar in stormy weather, attests the fact of the pebbles being in perpetual movement. The greater part of the shingle rolled up by the wave in an oblique direction is carried back on its return in a direction normal to the beach; but some stones, and these frequently the largest, remain at the place to which they are lifted. The movement of the drift is therefore of a zigzag form. These breaking waves of the flood-tide approach and retire in sets, the ninth or tenth, according to circumstances, being generally the highest. The stones thrown up on the crest of the wave are gradually lifted higher up the beach as the tide rises; and at high water there is always a certain quantity carried by the crest of the highest wave above the reach of the retiring waves of the ebb-tide.

In addition to the impulse imparted to the pebbles by the momentum of the breaking wave, the material is moved along by the current generated by the wave after it has broken on the beach. The velocity of this current has been estimated[1] as that which water would acquire in falling a distance equal to the height of the wave, or $V = \sqrt{2\,g\,h}$, h being the height of the breaking wave. The velocity due to a wave only 1 foot high would be about 8 feet a second, and therefore capable of moving pebbles of considerable size.

The material moved upwards by these tidal waves varies in size between grains of sand, pebbles weighing only the fraction of an ounce, and stones weighing 5 to 6 lbs., the average weight of the pebbles being about 4 or 5 ounces. With a perfectly calm sea, the Author has observed, on a shingle beach in a sheltered

[1] Minutes of Proceedings Inst.C.E., vol. lxxxii. p. 323.

position, numbers of stones moved upward and forward, which weighed from 4 ounces upwards when out of the water, and single stones weighing as much as 6 lbs.; and shortly before high water, pebbles weighing $1\frac{1}{4}$ lb. were rolled upward and forward, and left on the bank. The ebb-tide also retires from the beach with an oblique wave-action, the direction of these waves being the same as on the flood; and although the waves roll down more pebbles than they carry up, there is always a certain quantity of material which is moved upwards and remains, pebbles weighing $\frac{3}{4}$ lb. being raised and left on the bank in calm weather. On a sandy beach, the line to which material has been deposited above the influence of the ebb can always be traced by the "wrack" or floating material left stranded at the limit reached by the highest wave, and on a shingle bank by a ridge and hollow. This tidal-wave action is continuous and operates twice every day. Allowing ten waves to a minute, and that the forward movement only takes place on the flood, no less than 7,200 impulsive movements are imparted to the material drifted in the course of twenty-four hours.

Beaches below Low-Water Level.

Except in very heavy storms, the beach below low water is not subject to movement. As already pointed out, moving shingle banks are always above the limit of low water; and it has repeatedly been shown that there is no travel of shingle in deep water. During and after the construction of the Admiralty Pier at Dover, divers were employed to examine the bed of the sea at the foot of the wall to ascertain whether any shingle was travelling eastward along the wall, and it was found that such was not the case, although there was a considerable movement eastward along the beach up to the groyne which extended out from the shore immediately to the west of the pier, and a large accumulation at Folkestone.[1] Instances are recorded of large stones and other heavy material being raised from the bed of the sea in gales and cast up on the shore.[2] While, however, the deposit of these heavy substances may be cited in favour of an increase and accumulation of a beach in stormy weather, the effect does not extend

[1] Dover Harbour Report, 1847. Evidence of Capt. Washington. Sir J. Coode's Report, 1873.

[2] Minutes of Proceedings Inst. C.E., vol. lviii. p. 284.

beyond the deposit of the heavier materials. The under-tow of the waves, as they break on the shore, if not of sufficient force to move back these heavy stones, carries with it the sand or small pebbles thrown up. It is found that, except when large rivers bring down a great quantity of alluvial matter, or where high cliffs, consisting of soft material, are being eroded, there is very little change in the formation of the sea-bed near the shore, so far as any historical records afford a basis of comparison. So long as the natural conditions remain unaltered, and the set of the tides is not interfered with by piers projected out from the shore, or other artificial works, the equilibrium originally established between the several contending forces remains.

The two principal forces at work are the tidal currents and the action of waves. So far as wave-action is concerned, the effect diminishes very rapidly as the depth increases. Gales that affect sandbanks covered with only a moderate depth of water occur only occasionally; whereas tidal action is constant and continuous. Submerged banks disturbed by the waves are therefore quickly restored to their normal condition by the tidal currents. It has been found that when there is considerable motion on the surface of the water, divers can continue their operations below the surface, although they may have to cease work from not being able to stand against the strong current which prevails at certain states of the tide. As to the effect of tidal currents on the movement of submerged sand-beds in tidal channels, and, as showing that this movement is one of oscillation and not transportation, an instance is recorded by Mr. Partiot,[1] which occurred at the mouth of the Gironde. A steamer was sunk by a collision opposite Verdon, and rested on her keel at the bottom of the channel in 6 fathoms at low water, the masts and chimney only showing. At the end of the ebb-tide, the sand was so scoured as to leave a space under the keel at both ends, leaving the hull only supported in the middle; and at the end of the flood-tide, the vessel was completely buried in sand, the sand-bed extending 100 yards fore and aft of the vessel and 50 yards from each side.

A careful comparison of all the charts from 1801 shows that on the north coast of France and Belgium there has not been any appreciable modification of the shores, the banks and channels occupying the same relative positions and depths. At Dunkirk, the works carried out since 1836 have caused the coast to accrete westward for several miles; but this advance of the beach

[1] "Étude sur les Rivières à Marée," H. L. Partiot. Paris, 1892, p. 56.

has not altered the limits of the roadstead. In the banks and channels of the estuary of the Scheldt there has been very little change since the beginning of this century, the alluvial matter brought down by the rivers being deposited within the estuary and not carried or deposited on the sea-coast. The same remark applies to the great range of sandbanks along the Netherlands coast. At Nieuport, the bottom of the sea has preserved the same form and the same depths since the commencement of the century. At Ostend, the Grande Rade tends slightly to deepen; the Petite Rade has not changed for one hundred years. In the channels in front of Blankenberge, no change is observable; and the Pass of Wielingen tends to deepen.[1] A comparison of the charts of the North Sea off the Kentish and Essex coasts in use at the beginning of the century with those of the present day shows very little alteration in the position of the sands or channels, the only change being a lengthening of the sand-beds, and, if anything, a deepening of the channels. Further up the east coast, the sandbanks between Yarmouth and the Humber, and in the Wash, so far as can be ascertained from ancient charts, remain in the same position as they were a century ago; and the same is the case with the sandbanks at the mouth of the Tay, the great sandbanks at the mouth of the Mersey, the Dee, the Ribble, and in Morecambe Bay. In all these cases there has been a certain amount of alteration due to causes which can be traced, and an accretion in the estuaries from alluvial matter brought down by the rivers or eroded from cliffs; but the main features of the channels and the great sand-beds remain probably in the same condition as they were left at the last great physical change of conditions.

Stability of Channels in Sand.

The same remarks apply to the channels which intersect these great sand-beds. Through the great mass of sand constituting the bed of the ocean between the south-east of England and the coasts of France, Belgium, and the Netherlands, there exist several deep channels lying between sandbanks, such as the roadsteads in front of Havre, Calais, Dunkirk, Ostend, and other ports of the coast, with depths varying between 3 and 15 fathoms; and on

[1] "Étude sur l'amélioration et l'entretien des Ports en Plage de Sable," P. De Mey. Paris, 1894; and Minutes of Proceedings Inst. C.E., vol. lv. p. 79.

the English coast, the Wallet, the Sunk, Barrow Deep, the East Swin, &c., with depths varying between 5 and 15 fathoms; also the deep inshore channel known as Yarmouth roadstead, running parallel with the coast for 21 miles, from Winterton to Covehithe, having a depth of 4 to 7 fathoms. In fact, the whole of the lower part of the North Sea consists of deep channels lying between beds of sand. These channels have retained their depth and width without change, so far as any records exist; and as the result of a comparison of the present condition of the channels from Dunkirk to Flanders with the ancient charts, the Belgian engineers reported "that these channels taken as a whole have been maintained in a most remarkable manner."[1] The sandbanks which bound these channels are all steep on their inshore side, and spread in a gentle incline to the offing. The outer Ruytingen Bank, which borders a channel between 5 and 6 miles wide, and between 14 and 18 fathoms deep, rises almost perpendicularly from the bottom on the inner side, having a gentle slope on the seaward side.

So also the channels through the Straits of Dover have retained their depths, notwithstanding the stormy character of the locality and the drift from the cliffs by which both sides of the channel are bounded. On the coast of Holland, off the Texel and in the Skaw between Sweden and Jutland, are vast sand-beds having permanent deep-water channels through them, the sides in many cases being very steep, dropping suddenly from shoal water to 10 or 12 fathoms. A sand-ridge in the North Sea, known as the Lemon Bank, near Yarmouth, extending for 20 miles, with a width of $\frac{3}{4}$ mile, is so steep on the east side that a vessel would strike the bank before obtaining soundings in 20 fathoms of water.[2] The Stroombank which forms the protection for the roadstead at Ostend, composed entirely of sand, exposed to strong tidal currents and the impact of waves from the sea, has a very steep slope on its inward slope, and a depth at low water in the channel of between 3 and 5 fathoms.

About half of the Wash on the east coast consists of sand-beds rising above low-water level. Through these run a great number of tidal channels. In comparing the Admiralty chart of 1829, the first reliable one which is to be found, with that of 1891, a period of sixty-two years, it will be found that, except at the upper end of the estuary, where training works have been carried out, there

---

[1] P. De Mey, "Ports en Plage de Sable."

[2] "North Sea Pilot."

is practically no alteration in the position or depth of these channels. The only change that has taken place has been in prolongation of the sandbanks in the direction of the flood-tide and a deepening of the channels. The approach to Lynn, Fig. 4, Plate 1, is through a mass of sand-beds, 8 miles in width, intersected by a number of tidal channels. The main navigable channel which passes through these sands has a sharp curve, its depth varying between 2 and 6 fathoms. Its position is the same, and the depth rather greater now than it was sixty years ago. The other channels leading to Boston and Wisbech have remained the same as they have ever been, so far as the sea-approaches are concerned; and the depth over the bar of Boston Deeps has remained unaltered.

Describing the estuary of the Gironde, Mr. Partiot says:—"If only a portion of the river be examined, the risings seem to indicate a filling up; but if the observations are more extended and carried over a longer period, it is seen that the risings correspond to lowerings in other places, and that in the arms of the sea, where all the alluvial matter from the river has been carried during many ages, there exist alternate movements, observations of which seem to show a recurring period; the discharge remains the same, and the divers effects which are produced tend to a mobile equilibrium which effects the conservancy of the estuary." It is unnecessary to multiply instances of the permanency of channels through sand, as a study of the charts of the coasts and estuaries of this and other countries will be sufficient to show that those quoted are by no means exceptional instances, and that, in fact, many harbours owe their existence to the protection afforded by long strips of sand which, running out from the coast, resist the action of the tides and waves and maintain their position.

These facts all point to the conclusion that there is little or no permanent movement of sand below low-water mark. A channel having at one time been established, and an equilibrium of forces set up, the momentum of the volume of water due to tidal action moving in a given direction between two banks of sand is sufficient to overcome any surface action due to winds and waves, and the channel consequently remains permanent, although the sides and bottom are of a mobile character; and this even in channels having a considerable curvature.

Dredging.

If this absence of change be established, it is fair to presume that channels through sandy estuaries may be permanently deepened and maintained by dredging without the aid of training-walls, provided that the direction be such that the flood and ebb currents shall be led so as to act in the same direction, and that the depth at low water shall be sufficient to resist any surface action due to wind.

Formerly when a harbour was situated on a coast encumbered with sand-beds, it was considered a hopeless task at any reasonable cost to provide a deep-water entrance. The perfection to which sand-pump dredgers have been brought has entirely altered the conditions, and has placed at the disposal of engineers the means of quickly and economically obtaining the depth of water required.

That channels dredged in sand without the aid of piers, training-walls, or scouring basins, can be made and permanently maintained is proved by works recently carried out, of which the following are the most notable examples. The main navigable channel to New York, Fig. 5, Plate 1, which passes through the outer bay to the Atlantic, was obstructed by four long shoals, over which the larger class of vessels could only pass at high water. The Government Board of Engineers, to whom the best means of improving this channel had been referred, advised that permanent results could only be obtained by stone training-walls, 4 miles in length, across these shoals from Coney Island to Sandy Hook, the estimated cost of these walls being £1,250,000. In spite of this opinion, it having been strongly urged that all that was required could be accomplished by suction dredging, sanction was given to experimental trials, which, proving successful, the channel was deepened by this process 6½ feet, giving a minimum depth of 30 feet at low water over a width of 1,000 feet at a cost of £258,551, the work being completed in 1890. The material removed was principally sand and alluvial matter. An official report made a year after the work was finished, stated that since its completion no shoaling had taken place.[1]

The entrance to the Mersey is through a vast mass of sandbanks. Through these banks there has always existed a navigable channel, the direction of which has altered slightly from time

[1] "Improvement of the Channels at the Entrance to the Harbour of New York," J. Edwards. Transactions of the American Society of Civil Engineers, vol. xxv. p. 573.

to time, partly owing to works which have been carried out on both sides of the river. At the junction of the channel with the sea in Liverpool Bay there has always existed a sand-bar, Fig. 6, Plate 1. Until recently no attempt was made to improve the depth over this bar, because the general opinion of engineers was that this could only be done at enormous cost by means of training-walls. By the use of suction dredgers, it has been proved that not only has it been practicable to deepen the channel over the bar from 11 feet to 23 feet at low water, over a width of 1,500 feet with a central depth of 24 feet, but that the channel so dredged has not only maintained its depth during the severe tests of the gales of two winters, but shows a tendency rather towards deepening than shoaling.

At Ostend, the channel from the harbour to the deep water in the roadstead, through the sand which lies all along the coast, has been deepened 6½ feet by dredging, giving now 16½ feet at low water, and has been maintained at this depth since 1886 by an annual dredging of about 130,000 cubic yards, of which about one-third is taken from between the jetties. A series of groynes has been constructed along the coast on the west side of the harbour to prevent the travel of the drift along the coast towards the harbour. The depth of the "Petite Rade," or outer harbour, varies between 4½ and 5½ fathoms, and it is separated from the main deep-water sea-channels by the Stroombank, Fig. 7, Plate 1, which runs parallel with the coast, and has only 10 feet over it at low water. In 1889 the Belgian Government gave instructions for a channel to be dredged across this shoal 2,000 feet wide and giving 16½ feet at low water of spring tides. The work was commenced in June 1890, and in November following a depth of 13·76 feet had been obtained. The work was commenced again in March 1891 and continued till October, the depth attained being 16½ feet. No dredging has since been carried out, and the depth is maintained, although there have been several violent storms. The total quantity of sand removed was 771,000 cubic yards, the distance of the place of deposit 2½ miles, and the cost 4·38*d.* per cubic yard.[1]

The bar of Charpentier, at the mouth of the River Loire in the Bay of Biscay, Fig. 8, Plate 1, consists entirely of sand. Through the middle of this, a channel 1 mile long and 660 feet wide has been excavated 8 feet by dredging, giving a depth of 15 feet at low water. This has involved the removal of 1,800,000 tons, which

[1] P. De Mey, "Ports en Plage de Sable."

was accomplished in three years, the work being completed in 1893. The deepening has remained permanent.

HARBOURS ON COASTS SUBJECT TO LITTORAL DRIFT.

A knowledge of the special conditions relating to the coasts, and of the natural forces in operation, is essential to the design of any works for the construction of harbours or for the improvement of access to tidal ports. The following principles, however, deduced from the facts recorded in the Paper, appear to be of general application.

1. That piers running out from the coast should be so projected as not to derange the main set of the tidal stream, and be so designed as not to cause an eddy current at the entrance to the harbour.

2. That the entrance to a harbour should be sufficiently large to prevent any strong set into it on the rising tide, and to allow of its being filled with a smaller velocity of current into it than the flood-tide has in front of the entrance.

3. That the piers should project from the coast into water of sufficient depth to be free from the action of littoral drift, and beyond the local influence of matter in suspension derived from the waste of cliffs or detritus brought down by rivers.

The first result of the extension of a harbour-wall or breakwater out from a coast where there is much drift of sand or shingle, is the collection of material in the angle formed by the pier with the beach, and also a gradual increase in the height of the beach for some distance away from the projecting wall. After the beach has extended out a certain distance this process stops, a state of equilibrium is reached, and further accretion ceases, especially where the precaution has been taken of arresting the destruction of cliffs by groynes or other projecting works.

The depth into which the piers have to be carried depends on circumstances; a depth of 2½ fathoms has in some cases been found sufficient. Sand and shingle have never been found to work round a pier having a depth of 4 fathoms. A strong illustration in proof of this is given in the works carried out in the construction of Madras Harbour. There is considerable movement of sand along this coast, especially when the monsoon is acting in conjunction with the set of the flood-tide, which is heaped up against any projection. As the breakwater for the harbour was extended out from the shore, a large amount of sand accumulated

on the beach in the vicinity, and also passed round the end of the walls as they projected from the coast into the harbour. As deeper water was approached, this effect became less, until it entirely ceased when the wall reached a depth of 4 fathoms at low water.[1] At Colombo during the construction of the breakwater, although the sand was heaped up as much as 12 feet in height during the monsoon, it exhibited no tendency to work into the harbour round the walls which were placed in a depth of 4½ fathoms. At Port Said, where the foreshore through which the piers extend is sand, and there is also a considerable amount of alluvial deposit in movement from the discharge of the Nile, during the construction of the breakwater there was a considerable growth and advance of the beach, and the sand worked through the loose concrete blocks into the channel; but after a time a state of equilibrium was reached, and there is no longer any apprehension of the material drifting round the ends of the piers and shoaling the entrance. In a report made by Admiral Richards, in 1870, he stated that supposing the rate of accretion along the coast proceeded at the same rate as when the piers were first constructed, it would take three hundred years before it reached the end of them, but he doubted whether it would extend much farther than it had then reached. At Dover, as already mentioned, the projection of the Admiralty Pier into 6 fathoms at low water stopped the accumulation of deposit which had previously taken place in the inner harbour; and no silting has taken place inside the pier. Some shoaling took place at the back of the wall soon after its construction; this, however, was not due to any littoral drift, but was caused by the strong tidal current which swept round the east end of the wall into the sheltered part, scouring out the bed of the sea where the current ran strongest, and depositing it where there was slack water.[2] In fact it was merely a transposition of material; the quantity of deposited material, however, being 10 per cent. less than that scoured away.

Ramsgate Harbour, situated on the same coast as Dover, affords an example where, owing to none of the principles mentioned above being observed, there is a continual accumulation of deposit, more than half its area being dry at low water, and the harbour being only maintained by continual dredging. The piers only extend into a depth of 4 feet at low water. The flood-tide does

---

[1] Minutes of Proceedings Inst. C.E., vol. lxx. p. 44. *Ibid*, p. 36. L. F. Vernon-Harcourt, "Harbour and Docks," p. 304.

[2] Sir John Hawkshaw's Evidence, Dover Harbour Report, 1875.

run truly across the entrance, but creates an eddy-current; and there is a strong inward set which carries into the harbour deposit derived from the waste of the adjacent coasts, and alluvial matter brought down the River Stour. Whitehaven is another example where shallow water at the end of the piers and an eddy-current result in the harbour being filled with silt. The flood-tide here passes the entrance of the pier, and striking Redness Point, eddies back along the shore, and carries the silt and sand direct into the harbour.[1]

At Newhaven, the breakwater, commenced in 1880 and completed in 1890, extends out from the shore 2,700 feet into 3⅓ fathoms at low water. The shingle travelling from the west has collected at the end next the shore, but not to any great extent. There has been some shoaling from the alluvial matter brought down from the River Ouse; but no shingle or sand has travelled round the end of the breakwater into the harbour, and no shoaling has taken place from material brought in from the sea.

At Kingstown there has been practically no silting in the harbour since its construction—nearly eighty years ago—although there are considerable sandbanks in the neighbourhood, and there are shifting sands immediately abreast the entrance. As at Dover, there was a certain amount of transposition of material, sand being scoured away from the western entrance and deposited on the other side. The freedom from deposit in this harbour is due to the entrance being in a depth of 4 fathoms at low water, and exactly in the fair stream of the ebb and flood current, and the opening at the entrance being so proportioned to the area of the interior that no perceptible current flows into the harbour.[2] The water enters this harbour bright and clear; and when the ebb-tide is coming off the sands in Dublin Bay, the water is running out of the harbour. At Howth Harbour, on the other side of Dublin Bay, where the same conditions do not prevail, and where the piers end in a shallow depth of 7 feet at low water, and where the tidal current does not run fairly in a line perpendicular to the entrance, continual silting has taken place.[3] At Tynemouth, although the sandy beach has advanced along the piers, it has not worked round the ends so as to shoal the entrance, but the sea approach has rather tended to deepen. It has been estimated that even if the present rate of progress of the beach is maintained,

---

[1] Minutes of Proceedings Inst. C.E., vol. lv. p. 95.
[2] Capt. Washington, Evidence, Dover Harbour Report, 1847.
[3] Gibbons, Evidence Dover Harbour Report, 1847.

which is unlikely, it would take 150 years before the accretion reached the seaward end of the piers.[1]

At Ymuiden, the projection of the harbour walls led to an advance of the sandy shore; but this effect ceased before the beach extended out far enough to compromise the depth at the entrance, which was in 4½ fathoms at low water. In this harbour there has, however, been considerable shoaling, necessitating continual dredging, due to material brought down the canal from the interior, and sand blown in during stormy weather from the sand-dunes in the neighbourhood, and driven in from the sea during westerly gales. These gales, beating on the coast, cause great erosion of the sand and alluvial matter, which is thus put in suspension and carried by the current across the entrance, where they are met by a strong current flowing directly into the harbour, which carries the suspended material with it.[2] The tidal current does not in this case run truly past the entrance and parallel with the outer pier walls, but its direction is disturbed by the canted shape given to the walls, which causes the eddy current referred to above.

Piers which are not carried out into sufficiently deep water only act as groynes, and stop the transit of the material moving along the coast, which after a time travels round the end of the pier into the harbour. An example of this is afforded by Lowestoft Harbour, where there is only a depth of 10 feet at the end of the piers at low water. During north-easterly gales, the shingle and sand accumulate so rapidly as to almost block the harbour, and continual dredging is necessary. An extension of the pier on the north side, a few years ago, arrested the travel of shingle and sand to a considerable extent; but the extension was not carried out far enough to prevent material working into the harbour.[3] If this pier, on the side from which the drift comes, was extended out into deeper water, like the groyne at Harwich, referred to before, the supply of shingle would be cut off, and scouring would probably take place instead of accumulation.

By the construction of groynes, placed along a coast on the side from which the material comes, the shingle and sand will be stopped in their transit, and the beach raised, stopping the erosion of the cliffs and thus cutting off the source of supply. The drift continuing to travel along the coast on the lee side of the harbour,

---

[1] Minutes of Proceedings Inst. C.E., vol. lv. p. 83.

[2] L. F. Vernon-Harcourt, "Harbours and Docks," p. 182. P. De Mey, "Ports en Plage de Sable."

[3] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 134.

and the supply being cut off, there will be no material left to be driven in by gales coming from the opposite direction to that from which the drift travels.

Conclusion.

The Author, in conclusion, desires the Paper should be regarded, not as an attempt at an exhaustive treatment of the subject, but rather as a means of directing attention to an intricate and difficult subject by suggesting deductions from the facts which he has collected.

The Paper is accompanied by eight tracings, from which Plate 1 and the *Figs.* in the text have been prepared.

Discussion.

Mr. W. H. Preece, C.B., Vice-President, said the members were greatly obliged to the Author for his interesting Paper, forming a contribution at once scientific and practical, and one that no doubt would elicit a discussion which would be valuable to the profession. He therefore proposed a hearty vote of thanks to Mr. Wheeler for the labour that had evidently been bestowed in preparing the Paper. Mr. Preece.

Mr. W. H. Wheeler said he wished to direct attention to the natural harbours formed by sand-spits, several examples of which were to be found on the coasts of America,[1] as those formations afforded examples which might be imitated with success in the improvement of river outfalls and harbours in situations where they were liable to be blocked by the travel of sand and shingle. These spits consisted of long, narrow banks of shingle or sand, which, commencing at some salient point on the coast, ran for a considerable distance in a direction parallel to the general coast-line, frequently curving round inwards at the extremity in the form of a hook, leaving a protected bay or harbour inside. The line of formation was almost invariably coincident with the run of the flood-current. These long, narrow spits formed natural breakwaters, and although exposed to the storms and waves of the open ocean, maintained their position in a remarkable manner, affording protection to the bay or mouths of estuaries across which they extended, from the incursion of the waves, to which their broad mouths exposed them, and in many cases also serving to deepen the navigable channels to which they gave access, and preventing the entrance into the estuaries of littoral drift. An examination of the conditions under which these sand-spits were formed, and the protection they afforded, confirmed the opinion expressed on a former occasion, that where it was desired to protect the mouth of a river or estuary from the drift of sand or shingle, and to maintain a deep channel, a single curved pier with the concave bend on the interior, extending out from the shore on the side of the estuary from which the flood-tide came, Mr. Wheeler.

[1] "Littoral Movement on the New Jersey Coast," by Lewis M. Haupt. Transactions of the American Society of Civil Engineers, vol. xxiii.; "Geological History of Harbours," by N. S. Shaler, Report of the Geological Survey, U.S., 1894: Washington.

Mr. Wheeler would be more effective in maintaining the channel and giving shelter to the entrance, than the plan that had been so frequently adopted of running out two piers at right angles to the shore. With the single curved pier, the drift would be arrested; and the tendency of any material that continued to travel, would be to extend out in the same direction as the piers: the flood-current working round into the channel, would maintain deep water at the outfall, while the ebb, running along the concave side of the pier, would concentrate its energy always in the same direction.

dmiral Sir eorge Nares. Admiral Sir GEORGE NARES, K.C.B., said the propositions put forward in the Paper were very startling to him, as a nautical surveyor who had all his life studied the movement of beach material. He would deal with the propositions *seriatim*. The first was, "that the vast deposits of sand and shingle in bays and sheltered places on the coast, are due to causes which occurred in remote ages, and which are no longer in operation." The accretion on some parts of the coast, and the wasting of others were ever continuing, ever producing changes; and he saw no signs of finality. The present sand-filled bays and estuaries were in almost all cases only the advanced sea-edges of far more extensive accretions, whether caused naturally or artificially, that occurred in remote times—a product of materials derived from the wasting of the sea-floor and the erosion of the sea-coast, carried shoreward by the action of the waves or wind-blown, and the alluvium carried down from the uplands. These bays and estuaries in their turn, if left to nature, would, in time, in many cases, be silted up, and form dry land, as surely as the large rivers were ever extending their deltas seaward. The second proposition was "that the drift which travels along a coast is due to the erosion of the cliffs, and is derived from the wasting of the land, and not from the sea-bed." The bottom of the sea, where subject to wave-action, and the deeper parts where subject to sea-currents of sufficient strength, were ever wearing out, the waste of the bottom being driven up on to the beach. The third proposition was "that the quantity of drift is limited, so that it may be entirely stopped or its movement controlled." That was not the case. Sand-motion along-shore, whether produced by wave-action or sea-current, was continuous, and could only be controlled by further works. As to Madras Harbour, he had been a member of the last commission of inquiry; and they prepared the India Office for the time, within a generation, when some younger engineers would have to carry out further works. On that coast, the sea-currents set along the land towards the south for seven and a half months, as compared

with the northerly run of four and a half months; yet, on account of the shorter period being accompanied by southerly or on-shore winds, the long period by more or less off-shore winds, the resulting carrying force was far in excess towards the north. The movement of the sand was still going on, and at the same rate as ever. At Port Said, it was a mistake to suppose that the littoral drift had been stopped; it would certainly continue so long as the alluvium-laden waters of the Nile discharged into the Mediterranean. But it had been fairly controlled by being allowed to run through the West Pier, and deposit its load in the sheltered water where it was readily removed by dredging. The case of shingle was slightly different from sand; but generally wherever shingle collected there was a sandy foundation, and as this was subject to accretion and rose higher and higher, so the shingle rose with it. He had had to watch the movement of material along-shore at Harwich. So long as the supply continued, no extension of the Landguard groyne would ever stop the movement of the shingle to the southward, for with the advancement of the groyne, the sandy foundation rose and afforded a raised base on which the shingle could rest and accumulate. If it were wished to stop the shingle at the groyne, the groyne would have to be extended as fast as the sand and shingle collected on its northern side; but this could have no possible effect in stopping the quantity coming from the northward, so long as the source of its supply was not cut off. The whole gist of the Paper was in the fourth proposition: "The travel of the material along the coast is due to the wave-action of the flood-tide." He knew of no sufficient wave-action emanating solely from the movement of tidal water along-shore to account for the transport of material that actually took place. Given a straight beach and an equal run of the ebb- and flood-tides along it, their transporting power would be practically equal; and some other primary cause must be looked for. His observations convinced him that the wave-action caused by along-shore winds was the chief moving power in transporting the shingle and sand, as low down as the wave-action extended. Below the wave-action, the tidal or other currents exercised a considerable transporting power. In this zone, the flood-tide usually exercised the greatest power; not merely because it was the flood-tide, but because, by the run of the tide up-river and over the shoals shorewards, it was drawn in closer to the coast, and so ran with a stronger velocity along-shore than the ebb-tide, which, affected by the out-river run, trended away from the shore, and encouraged an eddy close to the coast,

Admiral Sir George Nares.

Admiral Sir George Nares.

which in its turn produced a longer run of the water in the true direction of the flood. This was notably the case at the mouth of the Humber, and at Landguard Point, Harwich. With regard to the remark that on the east coast of England the general drift was towards the south, in a direction contrary to the prevailing south-westerly wind, if the prevailing wind was an off-shore wind, it was unable to create an effective wave-action, and necessarily could not combat with the prevailing on-shore winds, which in the North Sea were from the north-east. Again, if a tidal current were the primary cause, then a continuous current in one direction all the year round should produce an equal or greater effect. There were many cases where that was not the case. At East London, on the south-east coast of Africa, there was a continuous ocean current setting to the southward. The tide struck the coast at right angles, and practically there was no constancy in its littoral movement close along shore; if anything the ebb ran to the northward. Yet the preponderating movement of the beach material was from the southward, in direct disagreement with the movement of the sea-current. That was decidedly due to the prevailing southerly winds being along-shore or on-shore winds, and the northerly winds being off-shore winds. The on-shore southerly winds produced a strong current inside the outer surf line, which gave rise to a great disturbance and carriage of beach material to the northward. With winds fairly direct against the land, this surf current on the south side of the harbour ran to the northward, and in the small embayment on the north side of the harbour to the southward, the two meeting off the harbour mouth. The fifth proposition was that the movement was only in the zone between high- and low-water mark. That was fairly true as regarded shingle; but the littoral movement of sand was met with at greater depths, and as low as wave-action extended. Below the wave-action, tidal or other currents caused a movement, but they often counteracted one another, and so led to the idea that in deep water transporting power was at a minimum. The movement of material along the sea-bottom was often considerable. In the English Channel it was so great in parts that, at some of the light-vessels electrically connected with the shore, the steel-wire covering of the cable was being worn out fast by the continuous rubbing movement of the passing sand. As instances of isolated sandbanks, there was the Varne Shoal in the English Channel, Smith's Knoll and Leman and Owers, off the east coast, each surrounded by water 100 feet deep. Although the motion due to the sea currents appeared to be fairly balanced,

there was at the bottom a large movement backwards and forwards of the material composing those shoals. Finally, "that channels can be effectively deepened on sandy coasts by dredging, and if properly directed will remain stable," applied only to cases where the depth was below wave-action, and where the flood and ebb tidal currents ran practically at right angles to the coast-line. The success of the Mersey dredging was due to this. If there were any littoral run of the tidal currents in disagreement with the prevailing wind-action, dredging would be the more necessary to maintain the channel. He knew of no channel through sand subject to a direct cross-wave action, which was maintaining its depth unless it were walled. Admiral Sir George Nares.

Mr. E. D. MARTEN wished to mention a practical example within his own knowledge having a considerable bearing upon the question under discussion. The River Severn was canalized for 42 miles above Gloucester; but below Gloucester it remained in its natural condition for about 25 miles, after which it became estuary and Bristol Channel, the navigation from Gloucester to the estuary being continued by a ship-canal. From Gloucester up to Tewkesbury the water was upheld by a weir which was overtopped by spring-tides, sometimes to the height of 6 feet, which proceeding up the river 13 miles to Tewkesbury, and occasionally overtopping the weir there, reached Worcester, 16 miles higher up. These high tides were laden with alluvium, which was dropped along the first 2 miles of the channel above the weir at Gloucester. During a dry summer 250,000 tons were thus brought up and dropped, which were washed out again during the following winter. But in a very dry summer the accumulation in the 2 miles nearly encroached on the proper navigable depth of the river at that place. The deposit resembled grey butter in consistency; and he had always considered that if it were left to cake and dry for a long geological period, it would turn out to be the very material now known as the lower lias clay. He had recently found, on the geological map, that about 40 miles down the Bristol Channel there was a large area of lower lias clay, so that probably an erosion of the cliffs of the lower lias clay produced the material which had given so much trouble on the Severn. For the last fifty years engineers had been trying to devise some means of getting rid of this source of anxiety, but hitherto unsuccessfully. Mr. Marten.

Rear-Admiral WHARTON, C.B., said he only spoke as a sailor who had travelled about the world and had kept his eyes open, and from his position naturally took a great interest in the Rear-Admiral Wharton.

Rear-Admiral Wharton.

questions under discussion. He thought the Author had attempted to prove too much in trying to reduce rather complicated movements to very simple formulas. In his statement that the deposits of sand were not due to causes at present in operation, he could hardly mean what the words appeared to imply, because the rest of the Paper showed that there was an enormous amount of sand, shingle, and other matter constantly in movement; and, given a certain number of thousands of years, what was now going on was, he thought, quite sufficient to fill up an estuary like Morecambe Bay. The sand and shingle (mostly sand) travelling along the coast, under whatever action, turned into the bay and naturally could not get out again. If Morecambe Bay were now cleared out, even in the course of their own lives there would be such a vast deposit of sand as to make it intelligible that in a few thousand years or less the bay would present the same appearance as it did now. A modified equilibrium was reached in all those cases; and the deposit did not go on so rapidly as it did in the earlier stages. With regard to the proposition that the continuous travel of drift along the coast was due to the wave-action of the flood-tide, he did not understand what the Author meant by the wave-action of the flood-tide. The flood-tide was a great wave in the ocean, several thousand miles long and a few feet high. In the English Channel, where it was retarded by the friction of the bottom, it was 200 or 300 miles long and a few feet higher; but how it could give off small waves to break upon the shore he did not understand. The waves that broke upon the shore were, according to his idea, due to the wind. It might be distant wind, or wind at some other time; but he could not understand how any wave, except an extremely long one, could be caused by a tide. He agreed with Sir George Nares, and other distinguished men, that the main motive power in moving drift along the coast was that of the waves breaking upon the shore at an angle from the direction in which the waves were the heaviest. It need not be the prevailing winds, because, as Sir George Nares had pointed out, in the North Sea, although the prevailing wind was from the south-west, it was an off-shore wind, and therefore could have but little effect. But the north-east wind struck also at an angle on the shore, and was the predominant wind, so far as works were concerned; and he knew of no place where the movement of the sand was not in accordance with the action of those winds. The Author had given instances round the coast of England. It was curious how, in many cases, the movement of the drift accorded with the general movement of the flood-tide, and no doubt the

flood-tide would have a greater effect than the ebb-tide; but he felt convinced, from his observations, that it was the waves, striking from the direction in which they were heaviest, that had the predominant effect. He could hardly understand the statement in the Paper about the permanence of the sandbanks. The great sandbanks in the North Sea remained chiefly as they were; and it would be astonishing if those enormous banks, many miles long and containing millions of tons of sand, were constantly moving, changing, and disappearing. The actions of currents and winds over a great length of time, were more or less uniform; and therefore the banks, heaped up by the action of the winds and currents, might naturally be expected to remain more or less the same. The astonishing thing to him was the amount of change that did take place in them. In the many surveys on the English coast, enormous changes were always observed. The survey of Yarmouth Roads had been completed this year, and it was difficult to recognize the sands. Where ten years ago there were deep channels, there were now banks; the shallow channels had deepened out, and the sands had been entirely changed. Millions of tons had moved. That was not incompatible with the sands remaining mainly in the same places; but it showed that the movement of sand was not confined to the area between low- and high-water marks, because the banks were all covered by 6 or 8 feet of water. In places where there were 20 or 30 feet ten years ago, there were now only 2 or 3 feet. It was the same in the Downs. The shape of the Goodwin Sands was entirely different from what it was a hundred years ago. Although they were formed on a great chalk bank, which kept them from moving very far, still the movement of the Goodwin Sands was as much as half a mile out and in. They were nearer the land than they had ever been, so far as any reliable charts could show. The consequence was that the channel inside was clear, and the shallows of 8 or 9 feet that existed a few years ago had been entirely swept away by the velocity of the current. Rear-Admiral Wharton.

Mr. G. F. Deacon did not take the view of some previous speakers as to the Author's propositions, though he agreed that some of them required limitations, and others slight amplifications. The first proposition no doubt referred to sheltered places, towards which there was no littoral drift in the present day; and that being assumed, he thought the proposition was perfectly true. That the drift travelling along the coast was entirely due to the erosion of the cliffs was not correct, unless the enormous quantities of gravel brought down by some rivers, were intended to be Mr. Deacon.

Mr. Deacon. included in that erosion. The drift from these two sources compensated for the loss from the gradual degradation of the shingle into sand fine enough to be carried by the waves into comparatively deep water, and deposited beyond the reach of tides and waves. He agreed with the proposition that the quantity of drift was limited, and therefore its prevention was a conceivable possibility; for example, by very long groynes extending into deep water all round the coast, works that engineers were not likely to have the opportunity of constructing. He assented to the proposition that littoral drift was confined to the zone lying between low- and high-water mark, provided a margin of a few fathoms above and below high and low tide respectively, was included. But when the Author extended his principles to a particular case, Mr. Deacon ceased to agree with him. He had stated, for example, that he had taken samples of water carried in over the bar of the Mersey on the flood-tide, and found them clear. Mr. Deacon had done the same, not only over the bar, but in many other parts of the Mersey. The bar was 11 miles from the entrance to the Mersey; and an enormous quantity of sand and silt was picked up between the bar and the entrance, and carried into the river. He had found that on a 21-foot spring tide, 100,000 tons of sand and silt were carried into the river. The Mersey, nevertheless, did not silt up, because the scouring energy of the flood-tide was equalled by that of the ebb-tide, reinforced by the land water, and by going down-hill instead of up. The tide rose in the upper reaches of the Mersey several feet higher than it did at the bar; and the greater head thus attained enabled it to carry the same quantity of silt down that was taken up by the greater initial velocity of the flood-tide. When divers went down on a flood-tide, they stood in rushing particles of sand of considerable size. The 100,000 tons he had mentioned did not include that bottom sand. A large proportion of the sand and silt was deposited before the tide had ebbed, and a nearly corresponding quantity was taken up, from the low-water channel which, owing to this erosion, travelled across the whole width of the estuary; and so an interchange took place, which was a balance of the accretion against the outward scour. In the Mersey, as in other estuaries, a regime had been reached, in which the bed had silted up to such a gradient, that the efflux was just competent to undo the silting performed by the influx. This regime would evidently be stable until a change in the conditions occurred. Accordingly, whatever might have been the original source of the sand and silt in Liverpool Bay, it was certain that the sand and silt now composing the

banks below high-water level in the Mersey estuary, had travelled to Liverpool Bay and back again an incalculable number of times. Mr. Deacon.

Mr. W. MATTHEWS (of Westminster) desired to draw attention more particularly to the movement of littoral drift along the coast, and the effect of running out a breakwater or pier across an active shingle drift. It had, he believed, been previously held that movement of shingle and drift along the coast was produced entirely by wave-action. The Author had referred to "further observations and new facts which have since become available" which appeared to him to demand a modification of the conclusions hitherto entertained; and he laid down the proposition "that while wind and waves are the agents which operate in eroding the cliffs and producing the drift, the regular and continuous travel of the material along the coast is due to the wave-action of the flood-tide." He inferred from a subsequent statement in the Paper that the Author entertained the view that the active agency in the propelling of littoral drift along the coast, was not wave-action, as hitherto regarded by some of the oldest and most experienced members of the Institution, but that the effects were produced by the action of tiny waves given off from the main body of the flood-tide. Along the south coast of England the flood-tide ran from west to east, on the east coast from north to south. Along the south coast, the littoral drift was also from west to east, and on the east coast from north to south; therefore the Author was right in his assertion that the travel of the beach on the English coast was in the same direction as the flood-tide; but Mr. Matthews dissented altogether from the proposition that that action was produced by the little waves given off by the flood-tide, and maintained that it was entirely due to wave-action. That view, he thought, could be supported by looking at what actually occurred. The heaviest seas on the south coast were those from the south-west; and on the east coast from the north-east. The direction of those seas corresponded with that of the flood-tide; and when a flood-tide and a heavy sea ran in the same direction, there were heavier waves. When the tide ran in opposition to the sea, there was a short choppy sea, the tide tending to run down the waves. He thought it was entirely due to the wave-action that the drift coincided with the direction of the flood-tide, and that the action of the little waves had no material influence in propelling the beach. No doubt many had stood, as he had, on the shores both of the east and south coasts during an absolute calm, when, without a ripple on the water, the tides were running as usual: there was no wave disturbance, and no travel Mr. Matthews.

Mr. Matthews. of the beach on the coast. With a long period of east winds, especially on the south coast, the shingle was driven back against the normal travel; and for a time the groynes were filled up higher on the east side than on the west. For that time, at all events, the shingle travelled in direct opposition to the flood-tide. Still the balance of the travel throughout the year was from west to east on the south coast, and from north to south on the east coast. He thought, therefore, that the results were well accounted for by wave-action alone. The Author had referred to a somewhat limited extent of shingle travel. At Hastings, the breadth of the shingle was from 200 to 250 feet. A large groyne was carried out there from the shore into about 10 feet at low water of spring tides, to form an extensive strand upon which the fishermen could beach their boats. That groyne for a time stopped the entire flow of the shingle. By taking cross-sections at different times on the same lines, it was found that in twelve months the accumulation was 60,000 tons. At Shoreham, he found that to keep open the harbour, without increasing the depth, required the removal of 120,000 tons of beach per annum, 70,000 tons of which had to be removed from the entrance. That showed that although the travel was not very great, yet it amounted to a considerable quantity during the year. The beach accumulated towards the top during fine weather and off-shore winds; and when a gale occurred it clawed off the material, and flattened down the slope. At Hastings and Brighton, the storm angle of a beach after a heavy gale varied from 1 in 10 to 1 in 12. The Author appeared to entertain the view that after the construction of a breakwater or pier across an active shingle drift, there was for a period a growth of beach on the windward side of the pier, or on the side from which the travel proceeded; that the beach accumulated up to a certain point, when a condition of equilibrium was established, and after that no further accretion occurred. The Admiralty Pier at Dover had been given as an instance. Having been connected with the Dover works for the last five years, he entirely dissented from the Author's statement of the effect of running a work across an active shingle travel. The time, in that case, must inevitably come when the drift would cause such an accretion on the windward side as would necessitate an extension of the works, or the passage of shingle round the end of it. The Admiralty Pier at Dover was run out into deep water, and the shingle did not pass round the end of it; but that was to be accounted for on other grounds than those alluded to in the Paper. During the construction of the pier the harbour works at Folkestone

were in active progress. The shingle was trapped by the works that were carried out from time to time to the westward along the coast, and Folkestone retained the residue. At the entrance to Folkestone Harbour there were some acres of accumulation of beach to the westward of the west pier, which represented the growth of the drift. It was not, therefore, right to quote Dover as an instance where a work acted in the manner stated in the Paper. Only recently he had to examine the east cliff at Folkestone with a view of ascertaining whether there was any method of protecting it in consequence of the abstraction of the beach to the westward; and he had found that the base of the east cliff was absolutely devoid of shingle, which showed that the travel was most effectually cut off, and did not go to Dover. Sir George Nares had mentioned the interesting case of East London in South Africa. Within his personal knowledge, the breakwater, which ran out into 30 feet of water originally, did not stop the travel of sand; and at present the accretion extended from the end right along the coast. The growth of beach and sand was very deceptive to the eye with regard to the running out of a breakwater across the travel. As the shingle or sand gathered layer on layer, the actual progression outwards was smaller and smaller every year, although the quantity was the same, because it was distributed over a longer length; and that might account for a seeming period of quiescence in the accumulation. He believed that where there was a drift of shingle or sand, and it was required to run a work across it, and to keep the mouth of the harbour open, it could only be done by an adequate backwater as at Yarmouth. In that case, the entrance ran out across an active shingle travel from north to south. The north pier overlapped the south, and by that means the shingle passed on its natural course across the harbour mouth, which was run down, and the entrance kept open by the backwater. At Lowestoft, where there was no backwater, the entrance could only be kept open by very expensive dredging. Mr. Matthews.

Mr. E. B. Ellice-Clark said the Author of the Paper had mentioned observations which he had made in conjunction with Sir John Coode and Mr. Matthews at Hove; and he thought that the bare figures might be misleading, unless the whole of the circumstances in connection with the travel of shingle at Hove were made known. While generally agreeing with a number of the propositions laid down by the Author, he thought the proposition that the travel of shingle was due almost entirely to the action of the flood-tide, was untenable in the face of the observations which had been made at Hove. His own experience Mr. Ellice-Clark.

Mr. Ellice-Clark. was confined to the portion of foreshore lying between Selsey Bill and Brighton, and from Deal to Margate. To build up any theories upon general statements, unless accompanied by details, might lead to entirely false conclusions; but his experience might be of some value, being founded upon observations carefully recorded, and extending over a period of fourteen or fifteen years. The observations made on the Hove, Aldrington, and Brighton beach furnished a typical case of what was going on all along the south coast of England. For more than 150 years there had been a constant accretion of the beach in front of Aldrington, the adjoining parish to Hove, and Brighton. It was recorded that in 1704 and 1705 tremendous gales, on the top of spring tides, denuded the whole of that foreshore; but subsequently, up to about 1876, great accretions took place. About that period, however, groynes were erected at Lancing; and the Shoreham Harbour Trustees threw out a long pier, which practically stopped the flow of beach. In January, 1880, 27,000 tons of beach were removed from 770 lineal yards of foreshore at Hove during one series of spring tides, as ascertained by a comparison of cross-sections taken of the foreshore about six weeks previously to that great gale, and immediately afterwards. The denudation of the beach continued very rapidly; and in 1883 Sir John Coode, in a report upon some works which Mr. Ellice-Clark had advised the Hove Commissioners to carry out, recommended that groynes and a sea-wall should be constructed. When the wall was about 10 feet above the normal level of the beach, the reflex action was so great in one part that, on the occurrence of a strong south-westerly wind during a spring tide in the summer, the beach was rapidly taken away from the face of the wall and the foreshore. Drastic measures had to be adopted to save the wall, because the denudation had removed the surface of the shingle down to within 10 or 12 inches of the foundations. A portion of the wall was secured by piling it in front; but it occurred to him that if shingle were deposited in front of the wall, there was every chance of its coming in, thus forming an artificial beach, and when the groynes were constructed it would be held in position. He thought the artificial deposition of shingle for sea defence some distance from the foreshore had never been previously attempted; 25,000 cubic yards of shingle were deposited from 400 to 800 yards from the face of the wall, at an angle of about 120° from the position it was hoped it would eventually occupy. The shingle could be seen 4 or 5 feet above low water at ordinary spring tides. During the prevalence of calm weather, the artificially deposited shingle was only flattened. If there was any

truth in the theory laid down by the Author, that the shingle was moved by the flood-tide, and not by the wind-waves, a good deal of the shingle so deposited would have been removed; but for about six weeks after the shingle was deposited there was no movement whatever. About the middle of September, however, the equinoctial gales set in at the top of spring tides; and the beach came rapidly up to the face of the wall. That demonstrated that the travel of the shingle, on that part of the coast, was due, not to the flood-tides, but entirely to the waves breaking upon the foreshore. Those who had had the management of the foreshore at Brighton and the adjoining districts, held that a good deal of shingle came up from deep water. That, he thought, was erroneous; because in the five or six years during which there was no travel of shingle at Hove from west to east, no shingle came upon the foreshore, as determined by accurate observations. He thought the whole of the shingle passed Brighton from west to east, that the flood-tide had little or no effect upon it, and that its travel was due to the waves. On the west side of Selsey Bill there was a great amount of beach. All round the bay eastward as far as Bognor, there was very little beach; but at Felpham, which adjoined Bognor, there was an enormous quantity of beach; and this, he thought, showed that the beach, though it travelled across that bay, travelled in very shallow water. It was not at all, to his mind, at variance with the proposition originally laid down by Sir John Coode, and which had been emphasized by Mr. Matthews, that the flood-tide had very little to do with the movement of shingle. Mr. Ellice-Clark.

Mr. J. Wolfe Barry, C.B., Vice-President, said judging from his own experience, he must demur to some of the general propositions put forward by the Author. He should not contradict the view that the drift along the coast might be controlled, because that depended on the works that could be undertaken and were financially possible; but that it could be stopped, he ventured to think was a mistake. Some *caveat* ought to be entered against any general proposition of that sort, lest it should be relied upon as correct in dealing with matters of great importance. He was not prepared to say that littoral drift could not be stopped in certain places; but as a general statement it should be received with much caution and qualification. An interesting example was afforded by the history of the entrance of the Suez Canal into the Mediterranean, which had given engineers of all nations plenty of opportunity for discussion and consideration, and had been viewed not altogether without alarm by some of those interested in the future of the canal. Mr. Wolfe Barry.

Mr. Wolfe Barry. From the very first, the same operations of nature were foreseen as had been proved by experience to exist and continue, namely that the great quantities of alluvium discharged from the mouths of the Nile, travelling under the influence of the prevailing winds, would endanger the entrance to the canal. It was anticipated that this drift could be dealt with by long moles deposited in the sea; and it was hoped that they would stop the travel of the sand until it reached so far seaward that possibly a more rapid current would take it away into deep water where it would be no longer dangerous. Periodical surveys showed that the shore had continuously advanced, and was still advancing seaward against the windward side of the western mole; and whereas when the works were started, the line of high water was at the site of the lighthouse, at the present time it was at least half a mile further out. The decrease in depth extended beyond the end of the long western breakwater; and the entrance to the canal was now dependent upon dredging, which, though not a serious amount in so large an enterprise, formed a considerable item in the ordinary expenses. With this large advance of the shore within the short history of the Suez Canal, it could scarcely be said that the deposits of sand and shingle were due to causes in remote ages, which were not at present in existence. These operations of nature were evidently still active; and it was impossible, in a situation such as Port Said, to stop the travel of shingle or sand except by building out large piers and groynes further away to windward, which, after all, only put off the evil day. He therefore entirely agreed with what Mr. Matthews had said, for really, after all, it was only a question of time when such examples of littoral drift would have to be dealt with in some way or other. It might be possible under certain conditions—by moles prolonged into a current of water which would sweep away shingle to a distance—to keep the entrance of a harbour open; but he wanted to protest against a generalization on such a point as that. Every case must depend upon its own conditions; and it would be exceedingly dangerous to assume that causes of deposit, such as he had alluded to, were no longer in operation. The French engineers of the Suez Canal, in concurrence with the International Commission, had dealt with the shoaling of the water round the end of the western breakwater at Port Said, by the removal of the deposit which was constantly coming from the westward in a novel manner. They had from time to time taken off portions of the crest of the breakwater in lengths of 200 or 300 yards, and allowed the sea to carry the sand over and lodge it temporarily to leeward of the breakwater. As the

quantity of sand to be dealt with was more or less constant, it was considered much better, and more economical, to let the sand come over the breakwater into a place sheltered from the westward, where it could be easily removed by dredging, rather than dredge in the open sea. That system had proved a great success, and was still being adhered to. This showed their entire appreciation of the fact that that travel had to be systematically dealt with; and he thought it would last as long as the Nile continued to bring down alluvium. In this instance there was no flood-tide to influence the travel, which must be traced to winds and waves, as had been so well alluded to by Mr. Matthews, with whose remarks he agreed completely. As to treating such matters as of small importance, he noticed that the Author himself stated that, in the Chesil Bank, 3,750,000 tons had been moved in one gale, which certainly was not an insignificant quantity for engineers in dealing with harbours which had to be maintained, or works which had to be designed to control such a state of things. Although he agreed with the fifth proposition, "That the regular and continuous movement of sand and shingle along a coast takes place only in the zone lying between low-water and high-water mark," it was necessary for engineers to recognize that the high-water and low-water lines were often continually changing in such places. As the deposit took place, the high-water line went further seaward, and with it the low-water line; and, therefore, the movement alluded to by the Author as between high-water and low-water mark, although true as between those points, yet as measured from any fixed point on the shore, it might shift much further seaward as the deposit took place. Though some of the propositions might be true in particular places, he did not think that the generalizations in the Paper ought to be accepted as governing laws in dealing with harbours and mouths of rivers. By a tidal wave he always understood that great operation of nature which was visible in the distance between points of high water along a coast or estuary at the same time. The tidal wave originated in the ocean, and was there of enormous length and insignificant in height, becoming proportionately shorter and higher as it approached shoal water. Even in places like the Bristol Channel, it was 20, 30, or 40 miles long; and he did not understand what was meant by the little waves given off by such a wave as that. Waves produced by wind were most potent agents, which determined and controlled the travel of shingle in various directions; and he quite agreed with Mr. Matthews that the action of the waves produced by the wind, plus the motion of the flood-tide, was a very much more potent agent

Mr. Wolfe Barry.

Mr. Wolfe Barry. in moving shingle or sand along a coast, than if the influence of the waves produced by the prevailing wind was antagonistic to the action of the tide. In one case it was wind plus tide, and in the other case it was wind minus tide. The expression "tidal wave" was very often used in newspapers in an incorrect manner, as for instance a ship being struck by a tidal wave. He confessed that he did not understand the Author's theory that a tidal wave gave off subsidiary waves, and so produced a travel of shingle along the shore; and he should need further evidence before accepting it as an engineering fact.

Mr. Sawyer. Mr. E. E. Sawyer was glad to find the Author's propositions were not allowed to go forth as approved by the Institution. He had laid down general propositions on matters which could not be so treated. In regard to each of his propositions, examples might be found to which they applied, and many others to which they did not apply. Take for instance the third proposition: "That the quantity of drift is limited, so that it may be entirely stopped or its movement controlled." In some cases it might be entirely stopped, as in the case of Dover, owing to special circumstances; that its movement could be controlled, engineers dealing with harbours where there was a littoral drift had been trying to show ever since they had considered the subject, and they had in certain cases succeeded; but that certainly could not apply to every case. The eighth general proposition was, "that harbours should be so projected as to derange the main set of the tidal current as little as possible"; and in No. 1 of the particular propositions it was laid down "that piers were not to cause an eddy current at the entrance to the harbour." In some cases it might be possible; in other cases it was not. In projecting two piers from a sandy coast, where the tidal current flowed parallel with the coast, the pier-heads could be put at an equal distance from the coast, and so parallel to the current; or one pier could be put ahead of the other; so that in every case, especially as the ebb-tide in very few cases flowed in an exactly opposite direction to the flood-tide, there must at times be eddies about the pier-heads. The second particular proposition stated that the harbour entrance "should be sufficiently large to prevent any strong set into it on the rising tide, and to allow of its being filled with a smaller velocity of current into it than the flood-tide has in front of the entrance." Of course this should be the case where possible. But an engineer was not often free to decide how wide the entrance was to be, especially with regard to harbours that had natural openings. For example, at Durban Harbour, Natal, there was a natural entrance

which had been made through the sand into a large back bay. Mr. Sawyer. At Madras, there was simply an entrance between the pier-heads. The flow of the tide into a harbour depended on the height of the flood-tide above low water, the width and length of the entrance channel, and the area that had to be filled inside; and he did not see how that could have any relation to what was called in the Paper "the current of the flood-tide," or how that current could have anything to do with it. It might in some exceptional cases, but in most cases it would not, and as a general principle it was inapplicable. Not only in the Mediterranean was there no rise or fall of tide: at Rio Grande do Sul, on the south coast of America, there was no tide. The maximum variation in level was 2 feet to 2 feet 6 inches, which depended upon the direction of the wind. He had had to project a harbour there, where the entrance was 1,500 metres wide and 10 miles long, and where there were enormous lakes at the back; but the great littoral drift along that coast could not be attributed to the "current of the flood-tide." The third proposition for laying out harbours was "that the piers should project from the coast into water of sufficient depth to be free from the action of littoral drift;" and it was added, "sand and shingle have never been found to work round a pier having a depth of 4 fathoms." He hoped more instances would be cited to prove the incorrectness of this assertion. He knew of two, one of them at East London, referred to by Mr. Matthews, where there was 36 feet of water at the pier-head, yet the sand came round it. At Durban Pier also, further up the same coast, there was at least 5 fathoms of water originally, and the sand went round it quite steadily, although there was no large accretion of sand in the outer angle of the pier. The Author had tried to lay down general propositions and rules for things which must be dealt with individually in each case. Madras and Port Said had been mentioned, which were supposed to prove the accuracy of the propositions. Sir George Nares had said that Madras Harbour did not support them; and Mr. Barry had said that Port Said Harbour did not. If Mr. Matthews had referred to Colombo, he might have said the same thing; but he showed that Dover Pier had not done what the Author assumed of Ymuiden Harbour. He was certain that the engineers would not agree that the silting was due to the shape given to the walls, but would attribute it to littoral drift, the sand coming into the harbour round the pier-head. The Author, besides trying to prove too much, had proved too little; for in each case where he stated the littoral drift had been stopped, he was bound to show what had become of it.

Mr. Smythe. Mr. A. J. HAMILTON SMYTHE wished to refer to the injuries affecting the stability of the adjacent land, which might be produced in certain conditions by artificial interference, either with the natural course, or with the rate of progress, of the littoral drift. A landslip occurred a few years ago at Sandgate, which was attributed to land-springs, and was dealt with by intercepting the drainage, which improved the district very much; but he thought it was doubtful whether the whole cause of what occurred was due to the action of land-springs. They had existed for ages, and many periods of wet weather had come and gone. At the time the slip occurred, certain peculiar conditions, artificially produced, seemed to have had a considerable effect upon the result. The prevailing wind was from the south-west, and there was a considerable travel of shingle along the coast. The superficial geology of the district consisted of the lower greensand formation known as the Hythe and Sandgate beds—beds of greensand overlying thin saponaceous strata known as "blue slipper," which, when charged with water, reduced considerably the friction between the sand-beds and the underlying beds. When the railway was made to Sandgate about twenty-five years ago, Hythe station was founded on a bed of rock, which proved to be only 6 or 8 feet thick resting on the "blue slipper," and it suddenly cracked, carrying the buildings forward. In the same way, the weight of the railway embankment so disturbed the equilibrium of the material on which it rested that the embankment subsided, and the ground rose between the railway and the sea. Shorncliffe camp was about 250 feet above the sea; then came a sort of foothill formed originally by detritus from the face of the cliff, next came the space on which Sandgate lay, and then the sea. In the normal condition, there was a considerable accumulation of shingle from littoral drift on the shore. In the original line of the coast between Hythe and Sandgate, there was a slight concavity, terminated in the east by the small headland where the life-boat station stood. The course of the littoral drift was towards Folkestone. For some years after the construction of the sea-wall between Hythe and Sandgate, there was a gradual reduction in the accumulation of shingle along the shore in front of Sandgate. The further progress of the drift was checked by the gradual extension of the railway-pier at Folkestone, where the shingle accumulated to a large extent. Either the rate of progress of the littoral drift along, and eastwards of the sea-wall towards Folkestone, had become greater than that of the compensating supply of shingle from the west; or, owing to the alteration of the direction of the current by the new sea-wall, from a sweep outwards to

a direct scouring action upon the shingle, the deposit in front of Sandgate was considerably reduced. When the landslip took place the foot-hill subsided. There was no subsidence between it and the sea, nor was there an uprising; but there was a general disturbance which cracked a number of buildings about the town. The slip might be directly due to the artificial disturbance of the equilibrium previously existing between the pressure of the mass of shingle on the foreshore, and the weight of the material in the foot-hill, facilitated by the wet weather and the land-springs. Mr. Smythe.

Mr. W. SHELFORD said the object of the Paper appeared to be in the first place to minimize the great masses of deposited shingle and sand which they were accustomed to consider exceedingly large, with the intention of showing that engineers might control the drift which remained, either by the use of the suction-dredger or by properly designed piers. With this object, the Author had sought to establish various propositions, the first of which was a little startling, and related to geology rather than engineering—"That the vast deposits of sand and shingle in bays and sheltered places on the coast are due to causes which occurred in remote ages, and which are no longer in operation." As they were close to two interesting deposits, he should like to put that proposition to a practical test. The first one was in the English Channel, where there were great masses of sand and shingle stretching from the Downs northwards to Yarmouth Roads, and beyond. Moreover, the harbours and river mouths on the northern coast of France, and on the coasts of Belgium and Holland, were sand-blocked. He had been accustomed to consider that that great mass of material was due to the débris resulting from the destruction of the connection of England with the continent, which, though having taken place in a somewhat remote age, was not much beyond the historical period, because the Goodwin Sands were on the foundation of an island which had been an English parish. According to the Author's theory, the flood-tide, or according to some speakers, the wave-action, came from the south in one direction, and from the north in the other direction, into that area. In either case, whether the littoral drift was due to the flood-tide, or the waves (he thought the latter himself), it seemed impossible that that great mass of material—the ruins of the connection between the island and the continent—could have got out of that area; but, on the contrary, the drift from north and south had probably increased it. The second deposit was in the Irish Channel, about which they did not know quite so much. From the Dee on the Mr. Shelford.

Mr. Shelford. south, to the Solway on the north, all the rivers, including the Mersey, Ribble, and others, were blocked with sand in great masses. Similarly there, the flood-tide and prevailing wind came round the north coast of Ireland, and also round the south coast into that area. It seemed to him that that material, which had probably originally come down the rivers, had remained there for ages, and that it could not get out on account of the action the Author had spoken of, which, on the contrary, had rather increased it. He did not think the Author intended to refer to any remote geological period, but to a period in which the causes, although not actually in operation at present, were analogous to those now in operation. The Author had stated more than once that the quantity of drift was limited. No doubt there were cases where it was limited, as for example, at Spurn Point. In 1869, Mr. Shelford submitted a Paper to the Institution on the "Outfall of the Humber,"[1] in which he described the then condition of Spurn Point as being exceedingly attenuated by the carting away of the comparatively small quantity of 30,000 tons of shingle per annum for road-making. The Board of Trade had stopped the removal, and at the same time instructed Sir John Coode to make groynes to intercept the shingle which remained. Before those groynes were put there, Spurn Point was travelling southwards across the Humber, by the drift of shingle from the north to the other end, where it remained. After the groynes had been in operation for some twenty-five years, the survey was re-made, and showed that the whole of the shingle had been intercepted, and that not only had the continuation of Spurn Point southwards, which had been going on for centuries, entirely ceased, but that it was slightly receding. That was an enormous advantage to the navigation of the Humber, and showed how limited the quantity of shingle was, and how a small engineering work could control masses of shingle. Similarly, in Liverpool Bay, where the bar was now being so successfully lowered by a suction-dredger by Mr. Lyster, he believed the success was due to the fact that the removal of the *débris* was quite equal to its supply—the supply being due only to the drifting of the sand into the channel, whence it was carried down by the ebb-tide and deposited in still water on the bar. He quite agreed with what had been said about the wave-action of the flood-tide. He hoped the Author would reconsider that point, for he thought there could be no doubt it would be easy to explain some of the phenomena that had been mentioned in a more simple manner.

---

[1] Minutes of Proceedings Inst. C.E., vol. lxxviii. pp. 472, 493, and 515.

Mr. W. H. WHEELER, in reply, said in introducing this Paper, he naturally felt he was opposing the tradition of the last fifty years, and that he might be thought presumptuous in setting up new theories in opposition to such eminent men as Sir John Coode and others; but he remembered that engineering was a progressive science, and that engineers were not in the habit of taking anything for granted. If the President had acted only on tradition, he would never have built the Forth Bridge. All he asked was that engineers would look at the facts he had cited and the inferences he had drawn, and give them a fair consideration. The Paper was written for a practical purpose. Certain harbours had been great failures, others great successes. He had tried to ascertain the reason; he had stated the facts, and tried to fit them to his theories. Many of the speakers had looked at the subject from a different standpoint. The Paper had not been written for geologists, to whom a million years were of no account. Engineers had to provide for much shorter periods; and if the harbours they designed lasted a hundred or two hundred years, it mattered little what would happen in a million years. To his mind, previous theories on the subject were utterly unsatisfactory. They had been taught to believe that the movement of littoral drift was due to wave and wind action; the same thing had been said by eminent men in the course of the discussion; but he was still undaunted. The south coast and the east coast had been referred to by Mr. Matthews; he did not venture upon the west coast, and had not considered the other parts mentioned in the Paper. He had given a great number of instances in the Paper, in every one of which the movement was coincident with the flood-tide. If it was a mere coincidence, it was a very singular thing. He hardly knew of an instance where the continuous movement of drift (he did not refer to the accidental effect of storms) along the coast was not in the direction of the flood-tide. There was another curious coincidence with regard to the wind. When the winds were the most active, blowing on the shore, they took the beach away; and when the wind was least effective, blowing off the shore, the beach grew up. Those coincidences did not seem to fit the wind theory, and he had tried to find a better one. It had been suggested by Admiral Wharton that, if Morecambe Bay were now emptied, it would fill up again in a thousand years. It would in a sufficient number of thousand years, because climatic changes would have taken place that might lead to the same results; but under present operations, those great masses of sand could not accumulate in any reasonable period such as they had to consider. He had been asked how a tidal wave could do what he had stated. He accounted for it thus: A tidal wave coming up a sea like the

Mr. Wheeler.

Mr. Wheeler. English Channel or the Irish Sea, did not advance with its crest at right angles to the coast, but went forward in a convex form. The centre of the channel being the deepest, there was the least friction; and this part of the wave moving more quickly than that at the sides, advanced until the side of the wave coming to an angle of 45° or less to the coast, flowed off at that angle and struck the coast; and as it struck the beach in shallow water, the wave was reflected back again, and that set up a number of small waves moving backwards and forwards, oscillating waves, becoming waves of translation and capable of moving material. Anyone looking at the sea on a perfectly calm day when there was no wind, a boat in the offing lying perfectly still without rising or falling, might see small waves perpetually striking the beach and moving the shingle. If stones were marked they might be seen travelling along. In his Paper he had mentioned instances in which, upon a calm day, stones weighing 6 lbs. had been lifted up by those little waves. It could not be the wind, because the movement of the stones was continuous. He could only account for it on the theory that they were small waves given back by reflex action, striking the beach, and so moving backwards and forwards. Controverting the statement in the Paper that the movement of the littoral drift was between the zone of high- and low-water mark—a different question from the movement of the channels in deep water—Sir George Nares had instanced the fact that the cables from light-ships were cut by the continual action of the sand going backwards and forwards. That movement was, no doubt, continually going on; and he had given an instance, at the mouth of the Gironde, where it was proved that the sand went backwards and forwards. That oscillating movement, different from the drift of which he had spoken, kept the channels open. The flood-tide carried the sand forward, and the ebb-tide brought it back again; it went seesawing and was never deposited. That was the great distinction to be drawn between tidal and tideless rivers, which Mr. Shelford had pointed out some years ago.[1] His statement about the Mersey had been challenged by Mr. Deacon. One of his propositions was that the matter that accreted in estuaries did not come from the sea, but from the land; and in support of that he had mentioned that the water coming in over the bar of the Mersey was perfectly clear, having no alluvial matter in it. He had also taken observations, and had found that there was a certain quantity of sand carried in with the flood-tide; and he went on to say that an equal quantity was moved

[1] Minutes of Proceedings Inst. C.E., vol. lxxxii., p. 2.

out at the ebb-tide. Did not that prove the argument advanced in the Paper? If the matter carried into the estuary was carried out again at the ebb-tide, that appeared to support his view that the matter accreted in the estuary did not come from the sea, but from the land. His statement that the littoral drift was produced by the wasting of the cliffs was also challenged by Mr. Deacon, who said that if there was no wasting of the cliffs, littoral movement would still go on, and it might travel all round the coast of England. He thought it was amply proved that if the supply of littoral drift was cut off there was no further movement, the beach became bare and denuded; and therefore it would be utterly impossible that it should travel if the supply from the cliffs was cut off, at any rate it could never travel all round the coast of England, because in every part of England it was moving in a different direction. It was stated by Mr. Matthews that Dover Pier had nothing to do with the stopping of the drift. He admitted, as the Author had said, that the shingle did not travel round the pier into the harbour; but he said that it was not Dover Pier that had stopped it, but Folkestone Pier. He did not care whether it was stopped at Folkestone or any other place near; it supported his argument that by running out a groyne the travel was stopped, and showed that the shingle was under control, and that was all that was wanted. It was stated by Mr. Matthews that the shingle was effectually cut off, and that the amount grew smaller and smaller each year, which went to establish his proposition, and he had cited the cases of Yarmouth and Lowestoft where the shingle travelled round the ends of the piers. Neither of those cases complied with his conditions, because neither of these piers was carried into deep water. He had made it an essential condition that the piers to be successful should be carried into deep water. The remarks of Mr. Ellice-Clark had tended to establish the proposition contained in the Paper, because he had said that although the tide had nothing to do with it, when the gales blew on the foreshore they cut the foreshore out. That was the proposition he had been trying to establish. Facts were also quoted by Mr. Ellice-Clark to establish another proposition in the Paper, viz., that no shingle came from deep water. In speaking of the Suez Canal, Mr. Barry had endeavoured to show that the deduction drawn in the Paper from that canal was wrong; but he had gathered from the Blue Books and the Government Reports, that when the pier was first run out the accumulation was very rapid, and that it then became less and less. [Mr. Barry here observed that the deposit was quite as great now, but was removed more quickly by

Mr. Wheeler.

Mr. Wheeler. the dredging.] One of the Royal Engineers sent out to investigate, gave the accumulation as being very rapid after the walls were first made, stating that the material travelled through the walls owing to the blocks being laid loosely, but that since the shore had grown up, this had to a certain extent stopped the drift. The matter there, however, was not sand or shingle, but alluvial matter out of the Nile, carried in suspension, not rolled along the bottom, and it could hardly be taken as an instance of tidal drift. While not agreeing with the Paper, Mr. Shelford had brought forward an instance that helped the Author, viz., that of Spurn Point. The shingle went across the Humber, and became detrimental to the navigation; groynes were put in, and they stopped the travel of the shingle. That, therefore, established the fact that the shingle was under control, and that, if proper works were erected, the travel could be stopped.

Correspondence.

Mr. Allen. Mr. G. T. Allen considered it was difficult to agree entirely with the views that the operations of nature were now so small that their results were comparatively negligible, and that the effects of former action only had to be dealt with. From his experience in the Island of Sheppey, there had been an enormous amount of material abraded from the cliffs at Warden. In comparing an old chart of the island, of about 1574, with the latest ordnance map of the district, he found there had been an abrasion of about 1,400 yards in width, amounting to a loss of 380,000,000 cubic yards in about 320 years, or considerably over 1,000,000 cubic yards every year. The annual width of the erosion, from the above figures, was over 13 feet, which was about double the rate given in the Paper for the erosion of the coast between Bridlington and the Humber; and this, coupled with the height at Warden, above 100 feet, made the actual rate of erosion five times as great. The material of which the cliffs were composed was clay, which, with the continual washing, was reduced to mud, sand, and shingle, the latter containing innumerable fossils, which denoted that the climate at one time was of a tropical nature.

Mr. Caland. Mr. P. Caland agreed with the Author that the drift along sea-coasts was not generally derived from the bottom of the sea, but from the erosion of cliffs and strands in high tides and storms, the larger pieces being slowly reduced by the sea and ultimately

ground into sand. On the Dutch shores of the North Sea, only sea sand was found, which was easily distinguished from river sand, both by the size of the grains and by its colour. He was quite in accord with the Author, that the travel of the drift was always in the direction of the flood-tide, which he thought arose from the fact that the flood-tide was stronger than the ebb; but he did not believe that the regular and continuous travel of the drift was to be ascribed to wave-motion during the flood, and still less did he believe that it travelled only between high and low water. On the Dutch coast, the motion of the drift was observed, not only between high and low water, but also in depths of 16 feet and more below ordinary low water, as, for example, between the old mouth of the Maas and the new approach channel to Rotterdam; and since the waves could only affect the bottom at these depths during very strong winds, it appeared to him that the movement of the drift along the coast was really to be attributed to the tidal current, the flood-tide carried the drift forwards, and the ebb, being weaker, was unable to move it back again, so that it advanced with each succeeding tide, provided no other cause existed to prevent it. The waves on low coasts had, he considered, no other influence than that they (as the Author also observed, p. 19), with strong off-shore winds, denuded, and, with on-shore winds, accumulated the beach. Mr. Caland.

Mr. A. E. Carey considered the propositions laid down by the Author were certainly not of universal application, and the problem of littoral drift appeared to him more complex than the Paper indicated. The late Sir John Coode, going down in a diving dress, had seen the shingle of the Chesil Bank moving at a depth of 8 fathoms.[1] The phenomena of shifting sandbanks beyond the limit of low water in many estuaries, indicated irregular movements of sand under the action of wind-waves and a consequent deep-water scour along sea-bottoms. How did the Author's theory of tidal action being the proximate cause of littoral drift square with the movements of shingle and sand on coasts where the tidal range was insignificant in extent? A notable instance of a foreshore in which vast movements of sand in suspension extended below low water, was that of the north-east knuckle of the Brazilian coast, immediately south of the line, where a belt of sand-bearing water, several miles in breadth, existed. On reef-sheltered foreshores, the waves not unfrequently could only strike normally to the coast-line, and their action was Mr. Carey.

[1] "Design and Construction of Harbours," T. Stevenson, pp. 19 and 20.

Mr. Carey. concentrated on a given locality. In such cases, the slope of the sea-bottom at that point was steep; and banks of shingle and sand accumulated on either hand, which the tidal action, being neutralized by the run of the waves, was powerless to disturb. The contour of the coast-line, the extent of the tidal range, the proximity of deep water, and the presence of coral or rock reefs near the shore, were conditions modifying the problem of the design of sea-works such as the Author had dealt with. In waters like those of the Persian Gulf, the presence of vast quantities of blown sand was the factor dominating the situation; and each locality had to be studied on its own individuality. Probably in the great majority of instances, solid works commencing at a depth of 3 or 4 fathoms, and channels dredged to that depth, would remain unmolested by drift. Reference was made in the Paper to Newhaven. No shingle had passed the breakwater from the west; but some sand had been deposited within its shelter, which had probably been brought in by easterly gales from the low-lying east foreshore. At Dunkirk attempts to outstrip the accumulations of sand had gone on unsuccessfully for 250 years. Dredging, however, had been vigorously carried on for the last fifteen years, and had produced a channel of a minimum depth of 3 metres. For the last three years the amounts dredged were :—

—	Channel.	Bar.	Foreshore.	Total.
	Cubic Metres.	Cubic Metres.	Cubic Metres.	Cubic Metres.
1893 . . .	61·500	194·575	231·060	487·135
1894 . . .	66·735	47·895	325·730	440·360
1895 . . .	81·520	87·500	285·000	454·020
	209·755	329·970	841·790	1,381·515

The width between the entrance-piers was about 200 feet, but this was now being widened to 135 metres. If the dredging were stopped, the harbour-mouth would infallibly silt up again, owing to the conformation of the coast-line; whilst the nature of the travelling sand and the widening of the entrance would tend to facilitate such action. The extremely fine sand on the Dutch, and portions of the Danish coasts, was very unstable, and when once in suspension was easily transported by feeble currents. Sharp irregular grit, on the contrary, lay closely compacted, and could with difficulty be brought into, or kept in suspension.

In a recent Paper by Professor John Milne, F.R.S., on "Movements of the Earth's Crust,"[1] he demonstrated that variations in

[1] The Geographical Journal, vol. vii. No. 3, March, 1896.

barometrical pressure and in the degrees of evaporation at different points of observation, resulted in earth-movements capable of record. How much more powerful in effect must be the bombardment of a steep sea-slope by the blows of heavy waves, accompanied by rapid changes in atmospheric conditions? In dealing with the motions of the earth's crust in relation to sea-level, Professor Milne gave the close of the palæozoic era and the early tertiary times as the periods of mountain growths and consequent ocean shrinkage, these changes having been synchronous with the formation of coal deposits. On certain portions of the Japanese shores, Professor Milne considered the upheaval of the coast-line and the recession of the sea, now in progress, to be exceedingly rapid; and he gave reasons for considering that a change of level at one spot of 10 feet had been brought about within fifty years; and recent variations over large areas, he thought, amounted to possibly 1 inch per year. In relation to littoral drift, these movements, whether progressive or occasional, were not to be disregarded. Mr. Carey.

Mr. W. DYCE CAY considered the causes of the formation of the alluvial deposits in the sea, as distinguished from the diluvial or boulder clay and stratified beds, were still in operation, that the vast extent of these deposits was due to the accumulated effects of these causes during long ages, and that it was not necessary to refer their production to some cataclysmal epoch. The long continuance of the same causes, and the unchanging nature of the natural phenomena produced a state of equilibrium in their effects on the sea-bed and coasts, and a regime which could be trained, but not safely disturbed without providing an equipoise. Mr. Dyce Cay.

For several years, when he had charge of Aberdeen Harbour, up to 1880, he had dredged 60,000 cubic yards annually of sand and silt brought down by the River Dee, having a basin of only 784 square miles, and deposited by it in the depths of the harbour artificially produced and maintained for navigation. Had it not been for these depths, this detritus would have passed out, and have been deposited on the sea-bed; whereas the dredging plant raised and deposited it well to seaward of the harbour. These figures would amount to 6 million cubic yards per century, or 600 million per 100 centuries, equivalent to a bank 60 feet high, over 7 square miles in area, and equal to a reduction of the level of the catchment surface by about 9 inches. The beach at Westward Ho was similar to the Chesil beach; and its origin and continued formation could easily be traced to the cliffs and rocky shore to the westward; and it was evident that a part of it had been recently rolled bodily landward, ruins of buildings

Mr. Dyce Cay. formerly within it now being left outside it on the foreshore. He attributed these beaches to the land under and behind them being about high-water level, for with a high coast, the shingle would have remained in front till it had been worn to sand by the waves, instead of being thrown over the bank by the sea, and finding shelter on the top and behind. Thus, at the Bay of Nigg, about ¾ mile south of Aberdeen Harbour, the granite rocks and boulders were worn down to shingle and sand by the waves; and though he removed the deposit almost entirely in successive years for making concrete for the harbour works, the sea always produced a fresh supply.

The tidal wave along the east coast of Scotland, from Aberdeen to Berwick, passed south during the flood-tide at 70 miles an hour, and so might be taken as 400 miles long from crest to hollow, but it had no similarity to a surface wave. He had often noticed the small wavelets as the tide advanced on a nearly level and dry foreshore, and in particular once in a large culvert at Aberdeen. On that occasion, the fresh water was passing down the culvert at about 4 miles per hour, and he noticed pieces of material, able to float in salt water but sinking in fresh, travelling up-stream with the inflowing tidal water at the bottom by successive impulses. These pulsations he attributed to the rising of the tide through confined and irregular channels, and against the action of surface currents.

Prof. Dawkins. Professor BOYD DAWKINS remarked that his enquiry into the origin of the sand and silt in the estuary of the Mersey, undertaken for the Manchester Ship Canal, confirmed the truth of the Author's conclusion, that the deposits in an estuary were not built up of materials swept in from the sea. He had examined the minute composition of the sandbanks in the Mersey, from Stockport inland down to the mouth of the estuary, with the following results. 1. The sand was derived from the angular and subangular glacial sand, forming the surface of the ground in the higher reaches, and differing microscopically from sand battered by the sea. The glacial sand had been washed out of the boulder clay. 2. The sand grains, almost entirely composed of quartz, became more and more rounded by friction in their journey down the stream. 3. In the estuary, and even as low down as the Great Burbo Bank, almost on the sea-front, these were present as more angular elements than the sea sand. 4. They were ultimately delivered into the sea, and contributed to form the ordinary sandbanks of Rhyl, Southport, and Blackpool, in which the rounded grains were more numerous. The silt also in the estuary of the

Mersey had been derived from up-stream, and not from the sea. The questions raised by the Author relating to groynes were very important. If the shingle, or sand, was intercepted in its drift along the shore by a large groyne, or a pier running into deep water, it was either arrested, or diverted into deep water, in which case it was lost to the shore. Instances of this were to be seen to the east of Brighton, Folkestone, and Dover, where the shore, bared of its shingle and sand, was exposed to the destructive effect of the waves. In his opinion, it was advisable to interfere as little as possible with the natural drift of the littoral deposits. From the experience of Mr. Henry Willett of Brighton, and of the late Mr. H. D. Pochin, it was clear that it was possible, by the use of small movable groynes, to encourage the accumulation of sand and shingle in certain spots, without interfering with the general regime, but they should not project more than about 2 feet above the surface. The disastrous effect of removing shingle from a shore-line was manifested by the rapidity with which the north-western coast of the Isle of Man was disappearing. Prof. Dawkins.

Mr. A. F. Fowler did not think the Author's description of the relative transporting power of the flood- and ebb-tides on the Yorkshire coast north of the Humber was accurate; and the alleged movement for a greater distance northwards, against the flood-tide, was not consistent with the statement that "continuous progressive movement is invariably in the direction of the flood-tide." The cliffs were eroded during the first half of the ebb equally with the last half of the flood-tide, and there would be portions of eroded cliff on the beach, to be acted upon by the first of the flood-tide. Moreover percolation through the face of the cliff on the fall of the tide would result in disintegration and falls of material near low water. Mr. Fowler.

After long consideration of the origin of the mud in the Humber, he had come to the conclusion that this silt, known as "warp," was the result of long-continued storm action on the Holderness coast and the north shore of the Humber. The wasted material, in an extremely fine state, was carried by the flood-tide up the Ouse and the Trent, where, being beyond the reach of storm action, it had been gradually deposited, forming the immense estuarine bed between the Ouse and the Trent, extending westward to Selby and southward to Gainsborough. Experiments made by Dr. Parsons of Goole, showed that the warp reached its maximum at Swinefleet, a little below Goole, and was most abundant in dry weather and at spring tides, and least in amount during floods at neap tide and during low water. Samples taken by him of the

Mr. Fowler. Ouse during high floods at York proved that the water was remarkably clear, the suspended matter not exceeding twelve grains per gallon; and, therefore, the mud did not come from above York. During the winter months the Ouse was deep below Naburn weir, the limit of the tidal flow, six miles below York; and the water was clear during both flood and ebb. During a dry summer, silt was deposited in such quantities as to raise the channel 5 feet above its winter depth. This accumulation generally commenced in May, augmenting slowly till the end of July, after which the rate of accretion was much quicker, the river attaining its worst condition about September. The winter rains effected an improvement which went on till April. During a wet summer, the summit of the deposit would be below Wharfe Mouth, 5 miles below Naburn; and in dry summers, the accumulation attained its greatest height about ½ mile below Naburn lock. In the dry summer of 1887, 317,000 cubic yards of material were deposited between Wharfe Mouth and Naburn lock; and during a still drier year, the deposit was so great as to require the floods of several winters to remove it. Between September and April, this bank of silt was washed down to Howden Dyke, 26 miles below Naburn; so that generally the navigation to York was obstructed during the summer by the shoals immediately below Naburn, whereas, in the winter, the chief obstacle was encountered by outward-bound vessels between Howden and Goole. Samples taken by him of the water in the river opposite Goole Docks,

SOLID MATTER HELD IN SUSPENSION IN SAMPLES OF OUSE WATER TAKEN AT GOOLE IN 1885.

Date.	State of Tides.	Low Water.	Half Flood.	High Water.	Half Ebb.
		Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.
February 13[1] . . .	Medium . . .	12	4	8	4
" 18 . . .	Spring . . .	48	120	144	64
" 23 . . .	Medium . . .	48	120	88	64
" 26 . . .	Neap . . .	16	16	16	12
May 5	Spring . . .	120	360	128	124

indicated that during the winter the water of both flood and ebb was as clear as in most other rivers. He estimated the quantity carried by spring tides in August and September at from 500 to 600 grains per gallon. In summer, at high water of spring tides, the water at Goole was perceptibly salt.

The clearness of the incoming water at the mouth of the

[1] On the 13th of February there were 2 feet of fresh in the river.

Humber, referred to by the Author, only applied to the summer; Mr. Fowler. for, during winter storms, the flood-tide below Hull was always turbid. The winter condition of the Humber and Ouse was muddiness at the lower end and clearness at the upper limit of the tidal flow. The muddy zone was in constant oscillation; and the river was clear in summer from Spurn Point to Whitton Sands, and in winter from Naburn lock down to Swinefleet, 2 miles below Goole. The muddiness of the water might be attributed in consequence, to the erosion of the Yorkshire coast; the gradual deposition of this wasted matter on the low-lying portions of the Ouse and Trent valleys; reclamation of these accreted lands from time to time without efficient means being taken to protect them; and, lastly, the re-encroachment of the tides, notably on the south side of the Humber above New Holland, coupled with the extreme friableness of the material comprising the bed of the Humber. Wave-action moved both the sand and boulders, of which littoral drift was composed; but while the latter frequently remained where thrown up by one wave until carried higher by the next, the sand was invariably taken back by the under-tow and removed in whatever direction the current might be travelling. A separating action was thus established, which, owing to its long continuance, resulted in the accumulation of isolated boulders, sorted out from immense beds of sand, thrown up towards high-water mark on the coast exposed to the dominant wind, and propelled along the shore by oblique wave-action.

Mr. L. Franzius was of opinion that the movements of the drift Mr. Franzius. along the sea-coast were governed by the action of the waves generated by the wind, and also by the action of the littoral current. The movement of the drift caused by the waves alone might be resolved into two parts, of which one coincided with the direction of the lines of soundings, and the other was normal to this direction. The first component, to which the littoral current had to be added, or else to be deducted if in an opposite direction, produced the continued travel of the sand and shingle along the coast. The second component formed the force which either threw the drift up on the shore, or drew it down into greater depths. With reference to the depth to which the action of waves extended, he was disposed to agree with the opinion expressed by Cialdi and Cornaglia in their books, that the influence of the waves was noticeable in great depths, even down to 650 feet in the open ocean. The examples brought forward by the Author, where sand and shingle were not found at the extremities of moles and the entrances of harbours, could in his opinion be more easily explained

Mr. Franzius. by assuming the movement of drift in great depths, rather than by the complete cessation of the travel of drift when a certain depth was exceeded. He entirely agreed with the Author that experience indicated that moles should always be carried out into an ample depth. He could only advocate the employment of dredging alone for deepening the navigable channel in estuaries, without the help of training works, in cases in which the circumstances were specially favourable. If the formation of a bar at the mouth of a river was due to the splitting up of the channel, it appeared to him more expedient to remove the cause of the formation of the bar by training the channel by spur dykes or longitudinal training-walls, and by the employment of dredging to accelerate the improvement, than to form and maintain a channel across the bar by dredging alone. In every case, considerations of cost must determine the course to be pursued. If the cost of the necessary dredging did not amount to the interest on the capital required for training works, it would be advisable to adopt the more temporary method of improvement.

Mr. Fuller. Mr. GEORGE L. FULLER said that about 2 miles eastward from the Castle Rock at Criccieth, a smaller point jutted out called "Graig Ddu," beyond which the shore surface consisted entirely of sand; though between it and Criccieth, there was a continuous shingle shore intermixed with boulders, the shingle on which appeared simply to travel to and fro. The Esplanade sea-wall, completed in 1884, started from the side of a headland, about 600 feet eastward of the Castle Rock, and about 1,500 feet north of its south point. The wall was 930 feet long, and terminated at its east end, where the beach was lowest, with a concrete return slope, 100 feet long, extending above the highest high-water mark, having a large culvert formed in it, with an outlet in the face of the wall, to provide for floods, and a small stream discharging at that end. The sea-wall reached 10½ feet above ordinary high-water level, and averaged 16 feet in height from the foundations (exclusive of a low parapet afterwards added), 10 feet thick at its base at the east end where the shore was lowest, and 4½ feet thick throughout at the top. The wall was built in sections, of concrete intermixed with boulders, and faced with sharp sand concrete, which, being worn by the action of the sea, was replaced by a stone face up to 4 feet from the top. The foundations were sunk to a minimum depth of 3 feet into the solid substratum of blue clay; and pipe-drains were built through the wall at frequent intervals, at the level of the top of this clay. Since the erection of this wall, a much greater pro-

portion of sand had been deposited on the beach in front of it than previously; though beyond the east return wall, shingle still predominated. A gradual flattening of the clay substratum of the beach had taken place all along in front of the wall, until at its deepest, or east end, the surface had reached a stable inclination of about 1 in 30 from low-water upwards, very similar to that of the same stratum about $\frac{1}{4}$ mile westward of the west end of the Marine Terrace retaining wall, on the west side of the Castle Rock, and nearly $\frac{1}{2}$ mile west of the wall on the east. Even before the Esplanade (behind this last) was finished, one of the storms which occasionally sweep away all loose shingle or sand from its front (to be gradually returned in calmer weather), exposed this under-stratum which exhibited signs of wear. He, therefore, added a false concrete beach under the drainage holes in 1885, 9 feet wide and $1\frac{3}{4}$ foot deep at the face of the wall, laid with a level bottom and tapering down to about 9 inches thick at the toe. During recent years, this false beach had been broken up in places, especially at the east end, by winter storms, and needed repair to secure the foundation of the wall from being undermined by the waves during a severe gale. Mr. Fuller.

Mr. C. F. Gower remarked that the Author was apparently of opinion that matter in suspension was not carried upwards any great distance by the flood-tide in a tidal river. Observations, however, with floats, and in other ways, showed that in the River Thames and in other rivers, matter in suspension might be carried upwards for several miles, the distance varying according to the amount of upland water coming down, and also with the direction and force of the wind. Where the amount of upland water was insignificant, as was the case for the greater part of the year in the River Orwell, the horizontal range of the tide on the flood and ebb was about equal, and floating or suspended matters near the surface were carried upwards as far on the flood as downwards on the ebb-tide. When, however, the wind blew strong from the south or south-east, the lighter matter, such as was discharged from the sewers, was carried a comparatively short distance downwards, and returned on the flood-tide much higher up, nor did the succeeding ebb carry it away. With the wind from the north, or north-west, the ebb-tide had the advantage, and the upper part of the river was kept clear from suspended matter. There was no proof that matter in suspension was carried any greater distance downwards on the ebb than upwards on the flood-tide; it merely oscillated backwards and forwards, in the absence of any preponderating force, from upland water, or of wind-waves; and it Mr. Gower.

Mr. Gower. drifted at last to shore, or was deposited in still water, till a change of tide or some other force again set it in motion.

Mr. Haupt. Mr. LEWIS M. HAUPT thought the scope of the observations and deductions in the Paper was comparatively limited, being restricted to the British Isles and the east coast of the channels as far as Ymuiden, with incidental reference to New York, Madras, and Colombo as to the effect of groynes. The premises did not appear to be sufficiently general, and might, in some cases, lead to erroneous conclusions. For instance, the first proposition as to the cessation of the causes creating deposits should be accepted with limitations. The second, as to the source of material, should be modified, certainly as applied to the extensive cordon of sand flanking the Atlantic coast of the United States, from New York Bay southward, for there were no cliffs to supply the material by their erosion; while the greatest banks, as at Newfoundland, Nantucket, and Hatteras, were at the salient points of the coast, from which the tidal currents set towards the bights of the bays, tending to remove rather than to supply material from these immense deposits. On the North Jersey coast, from Elberon to Long Branch, a clay and gravel bank, about 30 feet in height, had supplied material for the maintenance of Sandy Hook, and the bar obstructing the New York entrance. Such cliffs did supply material, but they were not the only source. The fifth proposition did not conform to his observations, nor would it seem from the context of the Paper to justify the conclusion that the "movement of sand and shingle is limited to the zone lying between high- and low-water mark." Indeed the Author cited a number of instances where breakwaters must extend to a depth of 2½ fathoms before the littoral movement of material could be arrested. The experiments made by placing boxes at various depths under water, as referred to in his Paper on "Harbour Studies,"[1] would seem to demonstrate the active agency of the waves in transporting material at depths considerably below the surface. This proposition was apparently contradicted by the eighth, where the piers were required "to be carried into a sufficient depth of water, and the littoral drift cut off by protective works." The statement in this latter proposition was only true in a limited sense; and serious damages had been incurred by the obstruction to silt-bearing currents in roadsteads, as most strikingly illustrated by the Delaware Breakwater. In his opinion, the silting up of estuaries was due to material brought in from the sea, as well as to that

[1] Library Inst. C.E., Tract 8vo., vol. 410.

carried down by floods from the uplands. He would refer to the changes in tidal rivers, and at Cape Henlopen, Delaware, and Sandy Hook, New York, and especially to the flexure of the mouths of rivers for many miles parallel with the coast, and often in opposition to the ebb movements, caused solely by the currents operating upon them for long periods. Types were furnished by Broadkill Creek, Del. (which debouched about 8 miles north of its natural outlet), and the rivers of the Carolinas, Cape Fear, Great Pee Dee, and others. The harbour of New York was unique in the existence of a resultant force which might have been utilized for the creation of a deep channel over the bar. The peculiar slough, nearly 1 mile long and ¼ mile wide, lying along the crest of the bar, athwart the currents, and at the western end of the channel, which had been maintained by the eddy formed by the currents, with depths of 54 feet, was an instance of phenomenal results produced by natural forces which only needed to be utilized to have given an ample passage over the bar.[1] Much of the testimony concerning littoral drift, and the dynamic action of the flood-tide, had been collected by such men as wreckers, light-keepers, and surfmen, whose observations of facts he believed to be reliable. These forced him to the conclusion reached by the Author, that such movements did exist in a direction opposed to prevailing winds, and that the motor was the angular movement of the waves and "breakers," especially during flood-tide. Hence it followed that the resultant direction of movement being known, the proper form and dimensions of breakwaters might be planned to arrest the silt and defend the channel. He might refer to a recent Paper[2] on the unprecedented results already obtained at Aransas Pass, Texas, by the partially completed breakwater he had designed, and which, though only commenced last autumn, had already removed one-half of the bar, at a cost of about £25,000. Information about drift, in addition to that furnished by the Author, would be found in the publications quoted below.[3] Mr. Haupt.

---

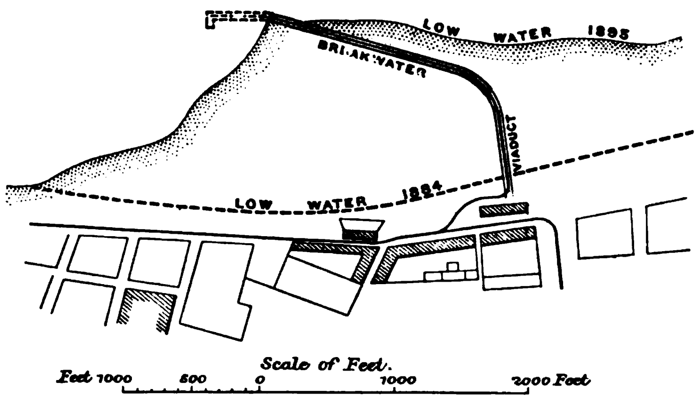
[1] Proceedings of the Engineers' Club of Philadelphia, vol. v. p. 300.

[2] "Commerce and Deep Waterways," The Journal of the Franklin Institute, vol. cxli., 1896, p. 81.

[3] "Harbour Studies," Philadelphia, 1886; "New York Entrance," February 6, 1886; "Delaware Breakwater," February 20, 1886; "The Physical Phenomena of Harbour Entrances," December 17, 1887 (Library Inst. C.E., Tract 8vo., vol. 410); Discussion on the "Dynamic Action of the Ocean in Building Bars," Am. Phil. Soc., March, 1889; "Littoral Movements of the New Jersey Coasts, Beach Protection, and Jetty Reaction," Am. Soc. C.E., September, 1890; "Harbour Bar Improvements," July, 1889; "Jetties for Estuaries," April, 1888; "Improvement of Tidal Rivers," October, 1889; "Law of Deposit of the Flood," Smithsonian Contributions to Knowledge, vol. iii., December, 1851; and sub-references in the above Papers.

Mr. Houston. Mr. J. L. HOUSTON observed that probably the most remarkable instance of littoral drift in the world was on the north coast of Brazil, from Cape San Roque to the mouth of the Amazon. The main South Atlantic current split near the Cape; and the northerly portion, forming the north equatorial current, carried enormous quantities of sand along the coast. The phenomena of this sand-stream were in great measure directly opposed to the propositions the Author sought to establish, except perhaps a modified form of No. 6. (1) Vast deposits of sand were accumulating year by year, the whole coast advancing, and sandhills of considerable height being formed. (2) The sand did not apparently come through the erosion of cliffs or foreshores, but appeared to originate from the

Fig. 9.



CEARA HARBOUR, BRAZIL

bed of the sea. (3) The quantity conveyed by the silt-bearing current was practically limitless, nor could its movement be controlled by practical measures. (4) Its movement was not directed by tidal action, but by the somewhat intermittent action of the trade winds and induced sea, together with the equatorial current. (5) This sand-travel, so far from being confined to the space between high and low water, extended frequently to a belt of several miles seaward, and a considerable distance inland where the drift sand was driven onwards by the wind. (6) The Author's proposition held good in this case, but only to a modified extent, the depth of water must be considerable, and the bottom even then not liable from its contours to assist the formation of banks. (7) Artificial channels through banks, subject to the action of a current of this kind, could not be cut, and still less

maintained. (8) Solid piers projected from the shore across a current of this character would certainly result in irretrievable silting. About ten years ago the construction of a harbour was commenced at the port of Ceará, where the phenomena referred to were probably at their worst. The works, designed by the late Sir John Hawkshaw, started from the shore by an open iron viaduct, about 750 feet long, the sheltered harbour area being provided by a solid breakwater, *Fig. 9.* As soon as the solid work had been commenced, silting resulted; and, notwithstanding every device and precaution, steadily followed the construction of the wall, until what should have been harbour space was simply so much dry land. Mr. Houston.

Mr. Edward Jackson thought one of the first considerations "affecting works carried out on the coasts for the benefit of navigation" was littoral drift, and the cause and direction of its movement along-shore: with regard to this, and the zone in which it moved, he was unable to accept the fourth and fifth propositions as giving a complete solution. His experience led him to conclude that the combined action of the wind and waves, and the current set up thereby, were the transporting agents, aided sometimes by the stronger tidal current; and the travel took place, certainly in the case of sand and silt, not only within the zone lying between low and high water, but wherever the action of the waves exerted their influence in disturbing the sea-bed. At Hartlepool, for instance, in constructing the breakwater in a depth of 12 feet at low water, sea-face blocks had to be carried down to the rock, through several feet of boulders and silt filling up a large cavity in the sea-bed. The clearing out of the beds for the blocks could be successfully carried on by divers in calm weather; but when a sea sprang up, and the work was stopped for any time, on resuming operations it was always found that the cavity had completely filled up again with sand and silt to the level of the sea-bed, showing the influence of wave-action. If the small waves, seen in calm weather, described as being given off from the main tidal wave, propelled the drift in the direction of the flood-tide during its flow, when the ebb set in a reaction would take place. Then unless these small waves were generated, as he believed, by the ground swell or rollers which incessantly kept the sea in motion to a greater or lesser extent, and moved in the direction of the prevalent wind, they would break in the opposite direction, on the ebb. The only progressive movement of the drift would be the difference of the propelling force of the flood-tide over the ebb or *vice versâ*. It was Mr. Jackson.

Mr. Jackson. stated, however, that both during flood- and ebb-tide, these small waves broke in the direction of the flood-tide. This indicated that they originated, not from the tidal wave, but from the ceaseless motion of the sea, and the movement of drift, therefore, must be traced to wind-waves. In a tideless sea, this theory of the small waves being given off from the main tidal wave would be untenable. At Madras, during the north-east monsoon, the movement of sand was from north to south, in the direction of the wind at that season of the year, and in opposition to the flood-tide. But during the south-west monsoon, it moved from south to north again in the direction of the wind at that season. Although, in the latter case, the flood-tide was in the same direction, and the movement was therefore much stronger, it was evidently not the flood-tide which was the primary cause of the littoral drift in the Bay of Bengal, but the wind and waves.

The term "prevailing wind" was somewhat ambiguous; and in tropical latitudes, the "set winds" or "constant winds" would better indicate the direction from which the drift would move. On the north coast of Brazil, where the shores were one continuous stretch of sand for miles, backed up with sandhills of varied height, the sand was all travelling westward. In proximity to the harbour of Ceará, close observations of these sand movements showed, that there was a travel of the sand in the direction of the wind and seas, which were practically continuous from the easterly quarters, with the tides and current setting in the same direction. The littoral drift on encountering the opposition presented to its normal movement by the breakwater sheltering Ceará Harbour, *Fig. 9*, p. 68, though minimised by 750 feet of open viaduct, had caused serious shoals in the harbour, necessitating dredging operations and further remedial measures. For the construction of a breakwater on a sandy shore, or where there was considerable littoral drift, it was all-important for the success of the work, that the design should admit of rapid construction, with abundance of materials and labour at hand to enable the breakwater to be pushed forward into a sufficient depth of water to keep the littoral drift in check.

Mr. Mann. Mr. I. J. Mann suggested that it was extremely difficult to generalise in the matters dealt with by the Author, as it was almost impossible to find two harbours identical in all their surrounding conditions. The causes which produced accumulations of sand and shingle on various parts of the coast had been in operation for a very long period. They were still acting, and

it was with their present effects that the engineer had to deal. When littoral drift existed in such enormous quantities, that, on a short length of coast, millions of cubic yards of sand and shingle were shifted in a single gale, it would be safer to consider the supply as practically unlimited. He had never seen any wave-action of the flood-tide, which could be traced to the rising of the tide. The wavelets or ripples referred to in the Paper as occurring in calm weather, were not peculiar to the flood-tide, but were equally observable with a falling tide, and appeared to be due to the disturbing effects of distant wind-waves. He could not agree with the Author, that the continuous movement of littoral drift was almost invariably in the direction of the flood-tide, an excellent example to the contrary being furnished by Howth Harbour, referred to in the Paper. This harbour was built by Government for the accommodation of the cross-channel service; its entrance faced north, and the harbour had been so completely filled up by the action of the southerly ebb-tide on the littoral drift, that it was now practically useless. With reference to the eighth proposition, it had hitherto been rightly considered that solid structures built across sandy shores—whether extending into deep water or not—acted like groynes and arrested littoral drift. That the movement of littoral drift was confined to the foreshore between high and low water was not in accordance with his experience, for he had found that the drifting movement took place below low-water mark, to depths to which the disturbing action of the waves extended. The Author's speculations as to the causes which produced littoral drift were interesting; but it seemed rather far-fetched to attribute one of these causes to the occurrence of tides at more frequent intervals in former times, a supposition involving many astronomical complications. Mr. Mann.

Mr. G. Mengin-Lecreulx thought the Author's opinion, that the great submarine banks were due to geological phenomena no longer in action, could not be correct; for the causes which had operated in the past were still in operation, though their action was doubtless slower than was often supposed. It was thus that the great deposits observed within the last fifty years in the upper parts of the Seine estuary, of over 400,000,000 cubic yards, had come straight, not from the Calvados coast, which could not nearly have furnished the amount, but from the submarine accumulation of the Seine bank, stretching in front of the mouth of the river. That bank, however, owing to its extent, had only to be eroded to a depth barely perceptible by soundings, to provide a considerable volume of accretion. By this means, in Mr. Mengin-Lecreulx.

Mr. Mengin-Lecreulx. certain situations, the materials brought in by the sea might lead to more difficulties than could be supposed from the statements in the Paper. The permanence of submarine banks could only be relative, since the causes which produced them were still in operation; but it was especially important to know at what depth below low water this permanence would be ensured, which observations indicated was very variable. At the head of gulfs or bays where the tides, waves, and silt-bearing currents converged and were concentrated, as in the Gulf of Gascony and the Bay of the Seine, the bottom was powerfully disturbed at depths reaching, and possibly exceeding, 33 feet. Hence came the accretion of the Seine estuary in all the parts withdrawn from the influence of the alternating tidal currents. The stability, therefore, referred to in the Paper was subject to restrictions. In the Seine, contrary to the views expressed by the Author, materials from the sea travelled up much farther than the saltness of the water, which practically ceased at Quillebeuf, and this might be due to the rush of the flood-tide.

The theory advanced in the Paper, as to the travel of the drift in the same direction as the tide, appeared to be confirmed by the facts with which he was best acquainted, with the reservation that it related to a general result, and that on any coast, the winds when blowing with force for some time in a certain direction might, as was often observed, for a time reverse the effect. Moreover, whatever might be the cause, experience would show at each place the direction of the littoral drift. The only objection to extending jetties into depths of 3 or 4 fathoms at low tide, to protect harbours from littoral drift, was its practical difficulty, amounting on some shores to almost an impossibility, especially with the necessity of rapid progress. The advice to make the entrance to a harbour large enough to prevent the flood-tide acquiring an increased velocity, followed by a reduction favouring deposit, was good in itself; but it was also necessary to obtain a sheltered area. This question, being governed by the local conditions of shelter, position, and tidal range, did not seem to admit of a general conclusion. The Author's opinion that, owing to the stability of submarine banks, channels deepened by dredging would be permanent, appeared to him to require many reservations. Natural channels generally maintained themselves, because they were the result of permanent causes; whereas artificial channels usually needed more or less maintenance. The most recent experience, however, proved that greater boldness might be exercised in this matter than was formerly supposed; and at the mouths of rivers,

there was in addition the ebb and flow of the tide. Especially when, as in the case of the Seine, the river did not discharge much solid matter, there was a permanent and constant longitudinal scour opposing the variable cross-influences of winds, storms, and eddies tending to fill up and alter the channel. He was in accord with the Author in considering that it was possible, at any rate theoretically, to obtain a permanent channel through an estuary by dredging alone, without training walls, by making it regular, sufficiently wide and deep, and in a direction coinciding with the course of influx of the flood-tide, with the object of giving the permanent longitudinal scour a decisive preponderance. The channel in the Seine estuary was a depression, generally winding, of at most 6½ to 10 feet below the banks which it traversed for over 9 miles. The directing action, due to this depression, was wholly inadequate, especially for the flood-tide, and the transverse forces held sway; whilst the materials of the bed, subjected to very strong currents, were in constant movement. According to the Author's views, which he shared on this point, the dredging of a regular and deep channel with sufficient rapidity, would not merely give the navigation a temporary relief, but the regime of the sands would be changed, the shiftings of the channel would cease, and the channel would be maintained at a moderate expense. With the distance, however, to be traversed, the initial formation of the channel would be a heavy task; but the distance was to be reduced by prolonging the training walls, and the improvement would be subsequently carried on in accordance with experience. On the whole, dredging carried out in a movable bottom, was often reproached with only producing temporary results; but the Author arrived at the conclusion that in many cases, on the contrary, the result would be practically permanent, with which he agreed. Nevertheless, even the accomplishment of this initial result would often require great efforts, and the technical problem would also involve a financial problem. Mr. Mengin-Lecreulx.

Mr. LÉON PARTIOT believed the distance which the materials from the sea ascended a river depended upon the slope and fresh-water discharge of the river, in relation to the total volume of water filling the channel, of which the Seine afforded an interesting example. The mean level of the quays at Rouen and at Havre differed only by 4⅓ inches, which proved that in early times the inclination of the river valley was very small between those points. On the other hand, the channel enlarged greatly below La Mailleraye, 42¾ miles above Havre, so that the river discharge had much less influence during the ebb below La Mailleraye than in Mr. Partiot.

Mr. Partiot. the narrower channel above; whilst the tides, which rose 23⅔ feet at springs at Havre, had a much greater effect. Consequently, the sands from the sea had travelled up to La Mailleraye, where they formed a sort of weir which kept up the level of the Seine nearly 16½ feet above low water of springs at Havre, and which had a gentle slope towards the sea. On this slope, constituting the estuary of the Seine, the main channel of the river was shifting and shallow; whereas above La Mailleraye, it had remained for the most part deep. At Rouen, there was an accumulation of coarse sand brought down from inland; whilst investigations below La Mailleraye showed that the valley was exclusively filled with sea-sand and silt, similar to the materials in the estuary; moreover, the tides deposited sea-shells at the sides of the Seine as far up as Villequier. This instance proved that the distance to which the sands from the sea ascended a river, depended on the highest point at which the flood-tide was stronger than the discharge of the river on the ebb.

Attention had been directed in France to the drift of shingle along the coasts since 1789, by Mr. Lamblardie's memoir[1] on the coasts of Normandy, which he traced to the waves throwing up the shingle and sand on the land in the direction at which they struck the shore. The waves in retreating, having lost their impelling force, flowed down the beach along the line of maximum slope, which generally was at an angle to their original direction. Consequently, the shingle and sand were carried along, at sea-level, to an extent depending on the angle the direction of the waves formed with the shore-line. The direction of travel might coincide with that of the littoral current, or of the flood-tide; but it mainly depended on the direction of the prevalent winds which blew towards the coast. The action of the waves due to the flood-tide was more regular, but these waves were small, and the littoral current had a low velocity, so that both the flood-tide and the littoral current had, in general, less influence than the prevalent winds, of which the coast of Gascony furnished an instance. The sands along that coast did not come from either the Garonne or the Dordogne, the deposits from which were readily recognized on the great bank seawards of Pointe de la Coubre, and could only come from the sea, which had a very flat slope along that coast. Although the flood-tide went from south to north along the shore, the sands travelled from north to south under the action of the prevalent north-westerly winds. Cape Ferret, formed by their advance, which had enclosed Arcachon Bay, had extended nearly 1 mile

[1] Library Inst. C.E., Tract 4to., vol. 22

further south since 1826. He was therefore led to the conclusion that the travel of shingle and sand depended distinctly on the prevalent winds blowing towards the shore, when they continued for an adequate period. Mr. Partiot.

The channels deepened by dredging at the mouths of the Hudson, the Mersey, and the Loire, and in front of Ostend, maintained their depth because they were carried out in the direction of the currents and facilitated discharge. But he considered it should not be concluded, from the success of these works, that continuous dredging should be resorted to for maintaining the access to rivers and ports, without the assurance that the necessary funds would never fail, and that other works would not produce the same improvement more economically. In the first event, there would be the danger of losing the improvements obtained, by the cessation of dredging, at the time when they might perhaps be the most useful, and of having to recommence the work when there might be still difficulty in providing the funds. In the second case, a yearly expenditure would have been undertaken, equivalent to the interest on a larger capital than would have sufficed for the execution of works which would have gained and maintained the requisite depths. The skill of engineers was often exhibited in discerning the requisite works, and in proving their value, so as to avoid burdening posterity indefinitely by works which would require costly maintenance, amounting almost to a perpetual reconstruction, such as certain dredgings in shifting beds.

General F. H. Rundall, R.E., agreed for the most part with the general propositions in the Paper, so far as his experience extended; but he was not sure whether the statement that the transportation of littoral drifts was due to the tidal current, was intended to attribute the movements to that force only, or whether the Author considered the terms tidal and littoral currents as synonymous. There was a littoral current quite independent of the tidal, which within a moderate distance of the shore possessed some transporting power. This was manifest in the Bay of Bengal, with whose coast-line he was the most familiar. In the lower portions of that bay, the tidal range and its consequent transporting power was very small. At Madras, the rise and fall did not ordinarily exceed 3 feet, while there was a considerable movement of sand and drift all along the coast. In the neighbourhood of the estuaries of the great rivers Coleroon, Kistna, Godavery, and Mahanuddy, the alluvium brought down during the flood season was carried out a long distance seawards beyond the influence of tidal action, and was transported by the littoral current for many miles in the direc- General Rundall.

General Rundall. tion in which that current flowed, and which varied at different seasons of the year. From the Kistna northwards, the prevailing direction of that current was shown by the embouchure of their several branches being turned in the same direction. In the lower portion of the bay, where the littoral current must be slight, the mouths of the rivers were deflected southwards, owing probably to the effect of the north-east monsoon. Point Calymere, south of the extremity of the Cauvery delta, and Point Godavery at the northern mouth of that river, were illustrative of the littoral currents in opposite directions on the same coast. At the Sandheads, the mouths of the Ganges and of the Bramaputra had all an easterly trend, while those of the Irrawaddy on the opposite coast trended towards the south-west. The discoloration of the sea, caused by the immense amount of alluvium held in suspension during the floods of those great rivers, extended a long way from the coast; and the littoral currents conveyed it north or south, causing in time a vast extension seawards of the coast-line. In the Godavery, the extension amounted to 2 miles to the eastward and 7 miles to the northward in thirty years. Consequently the Coringa lighthouse, originally built almost at the edge of the surf, was left 2 miles inland; while the soundings decreased so far out to sea that the light had to be raised 15 feet. That alluvial deposit was not, so far as he was aware, ever removed or carried in an opposite direction. In the thirty years which had since elapsed, Point Godavery had been extended several miles farther north; while the Bay of Coringa had become so shallow that the anchorage had been shifted to a corresponding distance, necessitating the construction of an entirely new lighthouse 12 miles farther north. The range of spring tides at that part of the coast did not exceed 6 feet. Owing to the enormous extent of alluvium covering the Sandheads, the tidal water running up the Hooghly carried a large quantity in suspension. The upper portion of the coast canal between Calcutta and Balasore, and thence on to False Point and the Orissa delta rivers, was fed entirely by the tides in the Hooghly. When first opened, the canal was filled by the flood-tide through the locks built at the several river-crossings, so that the canal became quickly choked with silt. To remedy this, a parallel supply-channel had been excavated, into which the flood-tide entered and deposited the greater portion of its silt; and the clear water was then let into the main canal. The stoppage of the navigation was thereby avoided, and the supply-channel could be readily cleared by manual labour. This action in the estuary of the Hooghly, where silt was carried

in suspension every flood-tide, was an instance of the transportation of alluvial deposit from the sea covering an area of over 100 square miles of the flats at the Sandheads. General Rundall.

There was a distinct littoral current along the Egyptian coast, occasioned partly by surface evaporation, and partly by the wind blowing right up the Mediterranean, and so raising its level at its eastern end. The accumulation above the outer breakwater at Port Said consisted chiefly of sand, the alluvium of the Nile being only conveyed in flood-time.

An example of the transport of drift by wave-action existed at the Port of Vizagapatam, midway between Madras and Calcutta. That town, in 1844, was threatened with destruction by the sea, which had completely washed away the beach, and was fast eroding the ground on which the town and fort were built. Sir Arthur Cotton erected a series of groynes at intervals along the threatened shore, nearly a mile in length. The groynes were made with large loose blocks of stone quarried from a bluff near the south end of the town. The erosion was lessened as soon as the groynes had been carried out only a few feet from the shore, and sand began immediately to accumulate. When the works were commenced, the beach was very steep, and the space between high- and low-water mark very narrow. By the time the groynes were finished, a long stretch of sand took the place of the steep beach, extending from the shore-line to the groyne heads which alone were visible, all the rest having become buried in the drift-sand. During and after their construction, the action of the waves was very visible, the movement of the sand taking place on the ebb as well as on the flood. The greatest accumulation was always on the weather side of the groynes, and varied with the wind and current at different seasons of the year. During the heavy storms which occurred annually in the Bay of Bengal, there was a considerable degradation of the beach; but the crest of the wave now never reached the shore-line, and the beach resumed its usual shape a few days after the storm had passed. Similar works had been carried out at Madras, Tranquebar, and other places along the coast, with similar results.

Mr. J. Watt Sandeman, from his observation of the causes producing and controlling littoral drift, agreed with all the propositions of the Author, with the exception of the statement in No. 4, that "the regular and continuous travel of the material along the coast is due to the wave-action of the flood-tide." He took exception to this statement, as based upon a new theory, for which evidence was lacking, and contended that no facts had Mr. Sandeman.

Mr. Sandeman. yet been brought forward to confute Sir John Coode's view, quoted near the bottom of p. 16 of the Paper. The Author had attempted to refute the theory that the direction of the littoral drift was determined almost solely by that of the prevailing winds, by stating that, as the prevailing winds in England were from the south-west, the movement of littoral drift should be in the same direction all round the coast, which was not the case, the fact being overlooked that on the north and east coasts, the south-west winds would be off the land, and so could have no action upon littoral drift. He agreed with the Author that on the east, west, and south coasts of Britain, except in certain bays, littoral drift travelled in the same direction as the flood-tide; but it also happened that the heaviest seas on these coasts were from the same direction, so this was not a proof that the flood-tide was the governing agent. Proposition No. 7 (p. 3) was only true when applied to channels in depths beyond the influence of wave-action.

He would suggest the addition of the following propositions, which he considered as now established in regard to harbours on sandy coasts:—(A) In the case of a river harbour upon a sandy coast, if the river mouth were sheltered by piers carried seaward to a depth at which wave-action ceased to affect the contour of the sea-bottom, no bar would form in the harbour entrance so long as the detritus brought down by the river was removed by dredging. If, however, the detritus were allowed to accumulate, it would gradually shoal the river mouth out to the pierheads, until by such shoaling the detritus was brought within the influence of wave-action, when a bar would be formed. (B) In the case of a harbour upon a sandy coast with piers carried seaward to the same depth as in case A, but without a river, no bar would form in the entrance, and no shoaling would occur in the harbour. (C) At all harbours on sandy coasts, where piers were not carried seaward to the depths before-mentioned, dredging would be necessary to prevent the formation of bars; and the amount of dredging required would be increased according as the exposure of the harbour was greater, and the pier-heads were placed in shallower water.

The first principle deduced by the Author for harbours on coasts subject to littoral drift (p. 28) would be almost impossible of attainment, as, where other considerations would allow, pierheads should be placed in alignment with the contour of the sea-bottom, which would, as a rule, be the most favourable position for enabling ships to enter the harbour during storms; but as this would frequently make the two pierheads in line with the tidal current,

the piers would of necessity interfere with its main set, and cause an eddy at the harbour mouth. Mr. Sandeman.

Mr. W. SHIELD considered many of the views put forward by the Author tended to endorse rather than refute the opinion which he, in common with many other engineers, held, namely, that the direction of littoral drift was, in the great majority of cases, determined almost solely by that of the prevailing winds. The east coast of England, being sheltered from south-westerly winds and being of very irregular contour, was not a good example from which to draw conclusions. However, on the coast of Aberdeenshire, northward of Peterhead, the prevailing southerly and south-westerly winds were so much affected by the trend of the coast, that the waves set up by them impinged on the shore from the south-east, the result being that the drift travelled in a northerly direction, while the strong flood current, with a velocity of about 3 knots per hour, ran almost due south. There could, in this case, be no doubt about the direction or persistency of the drift, since it pushed the mouth of the River Ugie round to the northward, and kept it there for a great part of the year. With north-easterly winds, however, the drift travelled south, and sometimes blocked the river mouth. He adhered to the opinion that prevailing, rather than dominant winds influenced the direction of littoral drift, if by "dominant" occasional very strong winds were understood. Heavy waves, set up by a strong wind, drew down beach material into comparatively deep water; so that although such a wind might, and almost invariably did, govern the direction of the drift for the time being, the quantity of material moved along the coast was not always so great as might be supposed. Soon after the subsidence of such a gale, the material drawn down was replaced by the action of the waves, and the prevailing wind again controlled the situation; but it was not contended that there were no exceptions to this rule. The Author's proposition "that the drift which travels along a coast is derived from the erosion of cliffs and the wasting of land, and not from the sea-bed" did not seem to be borne out by facts. Mr. Murray had mentioned that shingle and chalk ballast thrown overboard from ships off Sunderland, at 7 to 10 miles from shore, in depths of at least 10 fathoms, were brought ashore in large quantities during violent storms, and cast upon the beach by wave-action.[1] It was ascertained by long-continued observations, that the travel of sand in Algoa Bay, South Africa, extended out to the 3½-fathom line. At present Mr. Shield.

[1] Minutes of Proceedings Inst. C.E., vol. xix. p. 670.

Mr. Shield. he was engaged in blasting and removing rock from the bed of the sea, in depths of from 10 to 30 feet below low water of spring tides. A very moderate sea was sufficient to throw up quantities of the smallest of the material thus disturbed upon the adjacent beach. He believed the Author would find that he had been misinformed in regard to the accumulations in Ymuiden Harbour being caused by material discharged from the canal. They took place before the bank across the mouth of the canal was cut through, and were due to sand travelling chiefly from the south, round the ends of the piers which were situated in deep water. The portion of the east coast of Africa referred to by the Author was Port Natal, with which Mr. Shield was well acquainted. The inshore current was the counter-current of the great Mozambique stream, and not a tidal current as the Author supposed. The direction of this current was constant, but that of the drift was not. The direction of the drift was generally from south to north, owing to the angle at which the rollers, produced by the prevailing southerly winds, impinged upon the shore. When the wind was from the north, the direction of the drift along the shore was southerly. This was proved, not only by the banking up of sand against the north pier, but by the fact that materials brought down by the rivers Tugela and Umgani, were on such occasions found scattered along the shore between those rivers and Port Natal. Nevertheless, since the prevailing winds were from the south-east and south-west, the prevailing direction of the drift was northward.

Mr. Vauthier. Mr. L. L. Vauthier remarked that he would only deal with the Author's view, in relation to the oscillating movement caused by the tides in the maritime part of rivers, that the deposits were brought wholly from inland by the freshwater discharge. He agreed with the Author in considering that the amount of alluvium brought in from the sea had often been exaggerated. Nevertheless, he thought the conclusions in the Paper were too absolute, and that particulars of the changes which had occurred in the estuary of the Seine and the adjacent sea-bed, in the last fifty years, might be of value. The physical conditions of the Seine, the training works carried out in the upper part of the estuary, and the changes that had resulted, had been previously described.[1] He would, therefore, confine himself to the changes indicated by the surveys of 1834, 1853, 1875, and 1880, in two zones, one comprising the inner part of the estuary, from a little

[1] Minutes of Proceedings Inst. C.E., vol. lxx. pp. 90-97, and vol. lxxxiv. p. 211.

above Hoc Point for a distance of 7,830 yards seawards, with an area of 30,770 acres, and the other outside the estuary, extending from the first for 5,220 yards further out, and having an area of 40,630 acres. In the nineteen years between 1834 and 1853, accretion to the extent of 120,000,000 cubic yards had occurred in the outer zone, or a shoaling averaging 1 foot 10 inches in height over its whole area, and of 48,000,000 cubic yards in the inner zone, equivalent to a shoaling of 11 inches over its whole area. In 1875, twenty-two years later, 320,000,000 cubic yards of deposit had taken place in the estuary above Hoc Point; and during the same period, scour had occurred in both zones, amounting to a removal of 207,000,000 cubic yards in the outer zone, and 114,000,000 cubic yards in the inner zone, forming together 321,000,000 cubic yards, a remarkable approximation to the accretion in the estuary above, indicating that, in certain cases at any rate, in the action of the sea on beds of sand and silt, a sort of balance was maintained between the accretion in one part and the scour in the adjacent regions. Between 1875 and 1880, a reverse movement took place, resulting in the moderate accretion of 17,000,000 cubic yards over the two zones. Later observations indicated that the inner zone only experienced changes within restricted limits, showing that the changes were becoming regulated. The factors operating in tidal seas on the movements in the bed of the sea near the mouths of rivers, and in their estuaries, were so numerous, so diverse, and so complex, that the establishment of general laws in such matters was of extreme difficulty. The only principle that, in his opinion, could be enunciated on this subject was, that in an ordinary river with an unstable bed, a sort of interdependence existed between the several parts. The same law regulated the still more complex movements in river mouths; and from thence were deduced the rules, to which observation had led, for the improvements in progress on the tidal Seine. The principal of these rules consisted in augmenting to the utmost the flow of tidal water, whilst co-ordinating the discharge of the ebb with the volume introduced by the flood. Besides the enlargement of the lower part of the trained channel, the object aimed at for the improvement of the Seine in the upper part of its estuary, was to harmonise the different portions of the channel, by giving the bed the widths, and the sides the lines best calculated to ensure a free flow in both directions, aided by dredging the shoals which the currents alone could not scour away. Mr. Vauthier.

Mr. L. F. VERNON-HARCOURT regarded the Author as somewhat of an advocate, in first stating the propositions which he desired Mr. Vernon-Harcourt.

Mr. Vernon-Harcourt. to establish, and then marshalling his facts in support of those propositions, with some important reservations. All harbour engineers understood by the term "prevailing wind," the wind blowing from the most exposed quarter facing the coast on which their works were situated. It was incorrect to state that the prevailing wind on the east coast of England was the south-west, with the object of ascribing the drift to the flood-tide, for in reality the strongest wind which mainly affected that coast was the north-east. The Author desired to attribute all littoral drift "to the wave-action of the flood-tide;" and if this were true, there would be no littoral current or littoral drift in tideless seas. These had, however, been observed in the Mediterranean going towards the west, down to considerable depths, in front of the Rhone delta, and towards the east across the face of the Nile delta, in the Black Sea from north to south across the mouths of the Danube, and in the Gulf of Mexico from east to west in front of the Mississippi delta. The Author had quoted an instance of the accumulation of littoral drift in a tideless sea, on the western side of Port Said Harbour; and it was impossible to suppose that forces which were in active operation in tideless seas should have no influence along the more exposed shores of large tidal seas. Moreover, the Author, when desiring to prove that none of the alluvium eroded from the Holderness coast could enter the Humber from the north on the flood-tide, promptly transferred the preponderating action from the flood-tide to the ebb, and stated "that each tide leaves the material 7½ miles further north than the point from which it started," in direct opposition to the flood-tide. If the flood-tide exercised such an all-powerful influence on littoral drift along the sea-coast, it ought also to manifest its action in large estuaries having a comparatively insignificant fresh-water discharge, such as the Mersey, and should drive the sands from the banks in Liverpool Bay into the inner estuary. Generally, however, a sort of equilibrium was maintained, with occasional fluctuations, which was only disturbed when the construction of training walls in an estuary, by withdrawing the scouring influences from the sides of the estuary, enabled the flood-tide to deposit permanently large volumes of material behind the training walls in the upper part of the estuary, which it had taken up from the sandbanks lower down, as had been observed in the Seine estuary. The muddy alluvium with which the Usk was densely charged was not brought down by the river, as stated in the Paper, but came up with the flood-tide from the Bristol Channel, as he had often noticed. He was surprised at the following statement in the

Paper: "In the Bay of Bengal, where the monsoon blows continually for several months, there are two movements of sand in opposite directions. During the north-east monsoon, the movement is from north to south, in the same direction as the wind; but as soon as the north-east monsoon ceases, the direction is reversed, and the drift moves in the opposite direction with the set of the flood-tide." The Author appeared to be unaware of the periodical occurrence of the south-west monsoon in the Bay of Bengal, though in the next sentence it was referred to as blowing in the Arabian Sea. The setting in of the stronger south-west monsoon caused the cessation of the north-east monsoon; and the Author, without knowledge of the meteorology of the district, had brought forward an instance, in support of his theory, which only proved that the direction of the drift changed in accordance with the change in the direction of the periodical winds. As the flood-tide was propagated from the ocean, it naturally approached the shore from the most open and exposed quarter, and therefore approximately coincided in direction, in most cases, with the strongest winds causing the greatest wave-action on the coast. In order to prove that the travel of drift along any coast was "due to the wave-action of the flood-tide," it would be necessary to show, first, that there was no wind to which this travel could be ascribed, and, secondly, that this wave-action really existed. The Author had not attempted to establish the first condition, but had contented himself with ascribing any drift coinciding in direction with the flood-tide to that agency, though he had acknowledged in his Paper that "the power of waves in heavy storms breaking on the shore to move material is almost beyond comprehension." The wave-action of the flood-tide depended upon the existence of a continuous series of waves, given off from the main tidal wave, breaking on the shore at an angle of about 45°, and large enough to move shingle along; but no such constant, regular phenomenon was observable on the sea-coast; and when waves rolled in at an angle to the shore, this was due to the oblique direction of the wind. He readily admitted that the flood-tide, in so far as it created a current, had some influence upon the travel of drift; but evidence was wanting of the powerful action along the sea-coast ascribed to it in the Paper. Piers carried out from a coast subject to littoral drift necessarily led to an accumulation of material on their windward side; and though he agreed with the Author, that the amount of drift was often limited, the piers could neither stop the drift towards them, nor prevent its formation, except so far as they protected the coast. The advance of the foreshore was Mr. Vernon-Harcourt.

Mr. Vernon-Harcourt. naturally most marked directly a pier, on being carried out, arrested the drift, as the deposit occurred in shallow water and in the angle formed by the pier with the shore; whereas later on, the accumulation extended over a longer shore-line, and into deeper water. It was impossible to stop the supply of drift brought down by large rivers like the Nile; and he had recently seen the current of muddy alluvium passing across the entrance to Port Said Harbour, and had inspected the accumulation of sand on the foreshore to the west. The sandy portion of the alluvium carried down by the Nile must either accumulate on the western foreshore, or deposit in the entrance channel; but there was a large area to be filled to the west of the harbour, and the deposit in the channel could be removed by dredging.

Mr. Walmisley. Mr. A. T. WALMISLEY stated that the theories advanced on p. 3 would read better in a report to an authority soliciting the Author's views, than in a Paper presented to the Institution. If *Fig. 2* was drawn to a natural scale, the upper layer of pebbles, "which is subject only to the thin end of the wedge of water," appeared rather steeper than experience indicated. Prior to the building of the Admiralty Pier at Dover, the old reservoir in the South Pier was filled at high water, and subsequently discharged by sluices in the outer end of the reservoir to clear the harbour entrance; but since the Admiralty Pier had been built, not a pebble came into the east bay round the head of this pier. The beach oscillated to and fro in the east bay at various seasons of the year, but gave no cause for anxiety because the groynes were carried up to the parade, and well below low-water level of ordinary tides. Upon the west side of the Admiralty Pier the beach had largely accumulated in recent years, forming a protection to the South Eastern Railway property near the station; indeed, so much had the beach accumulated, that it would be necessary to dredge some of it away, to obviate the stern of the Dover-Calais passenger steamships running into the beach at low water, if the new landing arrangements recommended by the late Sir John Coode, east of the pier, were not decided to be shortly carried into execution. At Dungeness, where there were only groynes to protect the "outfall from damage," the foreshore was continually scoured out from the Hastings side of Dungeness Point and accumulated at the point, the loss of foreshore being an anxiety to the Denge Marsh Level Commissioners.

Mr. Webster. Mr. JOHN J. WEBSTER deemed that the Author's first proposition "that the vast deposits of sand and shingle are due to causes which occurred in the remote ages, and which are no longer in operation," hardly tenable; for whatever the causes, whether they

were glacial action, the transportation of material by melting glaciers and icebergs, oceanic currents, seismic eruptions, or atmospheric disturbances, the same causes were undoubtedly still in operation, imperceptibly, as they were then; for the "last physical great change of conditions," to which the Author referred, was not yet completed. Were it not for the construction of protective and other artificial works, the British coast-line would be considerably altered. The source of the drift was not only the erosion of the cliffs, but also the detritus brought down by great rivers, especially when they discharged into a tideless sea. The Author stated that "it is contrary to all known laws of tidal action in rivers for material to be carried upwards from the sea to any great distance," and gave the Humber and Mersey as instances. Out of numberless observations recorded by engineers and others, the Author was the only one who had not found the incoming water of the Mersey and the Humber heavily charged, with sand in the former case, and alluvial matter in the latter, especially after a storm. The composition of the banks in the estuary of the Mersey was sand, which had undoubtedly come in from the sea, though it was gradually being contaminated by the filth brought down by the rivers from the towns above. The composition of the banks of the Humber was mud, part of which had been brought down by the Ouse and the Trent. But just as the banks in the Mersey were of sand and not alluvial matter, and were consequently not brought down by the rivers, but supplied from the immense banks of sand in Liverpool Bay, so also were the banks in the Humber partly supplied from the immense amount of alluvial matter washed from the east cliffs. In his attempts to disprove this by his oscillation of the tidal-wave theory, the Author entirely ignored the important fact, that in the River Mersey the tide flowed for only five hours, but ebbed for seven and a half hours. Consequently part of the matter brought in by the flood-tide had time to settle during the ebb; and it was thus that the banks were formed in estuaries from sources in the sea. The Author presumably obtained his samples of the "bright and clear" water near the surface; the water, however, was more heavily charged with sand near the bottom. The Author's proposition that "the quantity of drift is limited, and may be either entirely stopped, or its movements controlled," was not supported by the results of many important works which had been carried into deep water for that purpose. For instance, the North Pier at Aberdeen, notwithstanding its extension into deep water, had failed to stop the sand travelling round its head; the bar still existed, and constant dredg-

Mr. Webster.

Mr. Webster. ing was necessary to allow even small vessels to enter the harbour at low water. Although the direction of the drift and of the tidal flow was the same in many places, this could only be regarded as a coincidence, and not as a proof of cause and effect. The direction of the tidal flow on the north coast of France was in many places from east to west, and the Author stated that the drift on that coast was principally from west to east. On the English coast the drift was, in almost every case, in the direction of the wind-waves. The small waves given off from the main tidal wave, as mentioned by the Author, were quite inadequate to account for the movements of the immense masses of shingle on the English coasts: and nothing less than the force of the wind-waves and tidal currents could possibly cause the great changes which were continually taking place. The Author's statement, that the contour of the sea-bed remained in a stable condition, was disproved by the results of deep-sea dredging, and ocean cable-laying, when strong currents—not tidal or due to wind—were found to be sweeping the bed of the ocean. Suction-dredging was an admirable method of removing large quantities of sand, especially with the well-designed plant used on the various works quoted by the Author; but it was decidedly premature to attribute permanency to the channels cut either in the Mersey or at New York, Ostend, and elsewhere, when they had only been completed a few years. The same combination of natural forces, which cut an entirely new channel in the estuary of the Mersey, might remove another one cut by artificial means. Time alone could prove whether channels cut in sand-banks by artificial means would remain permanent or not, without the assistance of constant dredging or protective works. In an estuary like that of the Mersey, where there were thousands of acres of sandbanks exposed at low water, it would be almost impossible to prevent a large amount of sand being blown into the channel during strong winds, which would have to be removed to keep the channel open; and the Author's statement, "that the channels so dredged showed a tendency rather towards deepening than shoaling," required confirmation, for it was said that below a certain depth the opposite action took place.

Mr. Wells. Mr. L. B. Wells was of opinion that the questions raised were of so complex a nature that much more information was required before any general proposition of a reliable character could be laid down. The Author appeared to have made out a good case for rejecting the assumption that "the direction of littoral drift is in the great majority of cases determined almost solely by that of the prevailing winds," which may have been adopted because the

prevailing winds and the flood-tide followed the same directions in the English Channel. If, however, the movement was influenced by the flood-tide to so large an extent as suggested in the Paper, then, in and about the Land's End, and to the eastward of harbours on the south coast of England, little or no deposit should be found on the foreshore, owing to the short distance from which detritus could be derived and the hardness of the rocks. Nevertheless, Whitesand Bay, immediately to the north of the Land's End, contained sand; and on the rock-bound coasts between Plymouth and Dartmouth, and of Pembrokeshire, the small coves and large beaches were covered with sand or shingle. The primary rocks rose abruptly from the sea along many miles of that coast, but wherever there was an indent or extended foreshore, it was covered with sand, which was found in the most exposed positions, namely, from Plymouth Sound to "the Start." Shingle was found along the less exposed coast to the east of "the Start;" and the bight of Start Bay was cut off by a beach of shingle, not unlike the Chesil Bank, extending $2\frac{1}{4}$ miles. The sandy bar of Salcombe Harbour, to the west of "the Start," was only just covered at low water of equinoctial springs, and had about 18 feet of water over it at high tide. The estuary inside was of considerable extent, the quantity of fresh water flowing into it being very small. The position of the bar shifted a few hundred yards from year to year, and appeared to be determined by the direction of the storms. The bar was in a state of mobile equilibrium; while the mud-banks, channels, and deeps inside changed but little. Mr. Wells.

---

10 March, 1896.

SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the Chair.

The President having referred to the recent death of Mr. James Abernethy, Past-President, read the following resolution, which had been passed by the Council and was concurred in by those present:—

> "That the Council learn with great regret the death of Mr. James Abernethy, Past-President, and desire to convey an expression of their sincere sympathy to Mrs. Abernethy and to the other members of the family."

The discussion upon Mr. Wheeler's Paper on "Littoral Drift" occupied the evening.

17 March, 1896.

Sir BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the Chair.

(*Paper No. 2898.*)

"The Lixiviation of Silver Ores."[1]

By JOHN HENRY CLEMES, Assoc. M. Inst. C.E.

IN most silver-producing districts, ores occur containing insufficient lead or copper to be submitted to the smelting process, and too impure to be dealt with by the wet-milling processes. In many instances the yield of silver from such ores is too low to permit their transport to metallurgical works where they can be dealt with economically, and it becomes necessary to treat them by such methods as can effect the purpose cheaply under the prevailing economic conditions. The presence in an ore of considerable amounts of sulphides, sulpharsenides, or sulphantimonides of the base metals, renders it irreducible by the amalgamation process. These compounds, the presence of even small quantities of which suffices to remove an ore from the free-milling category, are, for the most part, limited to iron pyrites, copper pyrites, copper glance, galena, blende, mispickel, and the various fahlores. Other varieties of these compounds occur not infrequently, but the cause of the so-called "rebelliousness" of an argentiferous ore is generally the presence of one or more of these minerals.

The almost universal method of winning the silver from such ores, was to first submit them to a chloridizing roasting, and then to treat the roasted product by one of the amalgamation processes. With certain types of these ores, the results obtained by this procedure were unsatisfactory, either the loss of silver incurred in the reduction, or the actual cost of the reduction was considerable. The use of sodium hyposulphite as a solvent of silver chloride in ores was proposed by the late Dr. Percy in 1848, and the first

---

[1] The discussion upon this communication was taken in conjunction with the two following Papers.

trials on a working scale were carried out by Von Patera ten years later. The development of the process was commenced in Sonora, Mexico, by Mr. O. Hofmann; and two or three lixiviation plants, designed and constructed by him, were in successful operation by the year 1870. The attention of mine-owners who had to deal with refractory ores was then directed to the process, and its use began to increase in Sonora, in the other north-western States, Chihuahua and Sinaloa, and in the Federal district of Baja California. It proved well suited for the treatment of certain classes of ore of frequent occurrence in those districts.

The extraction of silver by the lixiviation, or Patera process, is effected by converting the silver salts contained in the ores into silver chloride, which is dissolved in a solution of calcium hyposulphite, from which the silver is precipitated by an alkaline sulphide. The three stages by which these reactions are carried out are, roasting the ore in admixture with common salt, leaching the roasted ore with a dilute solution of calcium hyposulphite, and precipitating the silver sulphide from this solution by the addition of calcium sulphide. The precipitation of the silver is attended by the regeneration of the hyposulphite solution; the addition of calcium sulphide to the solution of silver chloride in calcium hyposulphite, in a proper proportion, precipitating silver sulphide and free sulphur, with the simultaneous formation of calcium hyposulphite. After the precipitate has settled, the supernatant hyposulphite is drawn off and pumped back to do duty as fresh solvent, and, under favourable circumstances, increases in strength and in volume. It is, however, subject to deterioration, partly from impurities and partly from its own instability; ores free from substances noxious to the solution are comparatively scarce, and the decomposition of the solution, from its slow oxidation, is always in progress. The remedies are, however, in most cases, of easy application, and the process is capable of dealing with a very wide range of silver ores.

With the exception of those containing a considerable percentage of galena, all silver-bearing ores, associated with these minerals, are effectively treated by the lixiviation process. Ores containing a small percentage of copper are treated with excellent results, and the rapidity with which the use of the process extended in Sonora is partly due to the fact that nearly all the silver ores found in that State, argentiferous galena excepted, are accompanied by some mineral of copper.

As compared with the means of extracting silver from its ores by roasting and amalgamating, the Patera process offers the

advantages of employing a much cheaper solvent than mercury, and of not requiring, in the treatment of the roasted pulp, any expensive machinery; power for stirring and grinding the roasted pulp is not needed, nor have a number of the working parts of the apparatus to be frequently replaced. The cost of working by either process is much influenced by local conditions, but, in general, if the nature of the ore is such as to require a chloridizing roasting, its contained silver can be more cheaply extracted by a solution of an hyposulphite than by means of mercury.

Plant Employed in the Process.

The plant for the lixiviation process comprises machinery for breaking and pulverizing the ores; roasting-furnaces; leaching- and precipitating-vats; and apparatus for treating the final product, or the silver precipitate.

The stamp-mill, roasting-furnaces, cooling-floors, and leaching works are set terrace fashion on the hill-side, a suitable slope for the purpose being one of 25° to 30°. The furnaces are placed with their long axes about at right angles to the contours of the hill, and at such an elevation that a railway may connect their feed-hoppers with the pulp-bins in the mill. The level space for the cooling-floor is set out a few feet below the points of discharge of the furnaces, and a narrow-gauge line from it passes over the tops of the ore-vats. Following the practice of mills in which roasting and pan amalgamation are used, the various departments of a lixiviation mill are generally collected under one roof. Ease of supervision is gained by the adoption of this plan, but in the event of a serious fire there is much risk of losing the whole plant. The bulk of the structure is of wood, even the roof covering is of wooden shingles, heavy import duties, and heavy rates of freight, placing the use of corrugated iron out of the question, and the climate is extremely dry. This risk renders it preferable to detach the furnace and leaching departments from the mill proper, and, in large establishments, it appears advisable to detach the leaching works from the roasting-sheds. At the Yedras mines the reduction works had to be arranged *en bloc;* fire-hydrants were placed at different points of the works, and were connected with water-tanks situated several hundred feet above the mill.

Grinding Machinery.—In northern Mexico the ores are almost always ground by a dry stamp-mill. In the 40-stamp mill built at the Yedras mines, the ore—much of which arrives partially broken from the picking-floors—is fed into two stone-breakers in the upper

part of the mill and from them drops into the ore-bins. From sliding-doors in the bottoms of these bins the ore is run into wagons and tipped into the dry kilns, and from the cast-iron spouts at the base of the latter it is conveyed to the self-feeders at the back of the batteries. Horizontal conveyors in front of the batteries transfer the pulp, or pulverized ore, to the inclined elevators, which raise the pulp to the hoppers in which it is stored. From these storage-hoppers the pulp is conveyed to the small hoppers over the roasting-furnaces. With the exception of wagon-filling from inclined spouts, tramming and tipping, the process of converting the stone into pulp of the required degree of fineness is accomplished entirely by mechanical means. The crushed product required by the lixiviation process is fine meal, as free as practicable from impalpable powder or slime.

The Yedras mines are situated about five days' journey from the coast, in a spur of the main Cordillera, at an altitude of more than 7,000 feet above the sea-level, and all freight has to be carried to them on pack animals. Heavy parts of the machinery had therefore to be divided into pieces not exceeding 350 lbs. in weight; a few parts of the apparatus which could not be so treated were attached to poles and carried over the mountains by large relays of men. The battery-posts were of the most thoroughly seasoned timber available. The feed side and front of the batteries below the line of the braces were unobstructed, so that the automatic feeders, the mortars, and the pulp-conveyors were readily accessible. Instances of the employment of the double mill for dry stamping are to be met with; in this type of mill two parallel lines of battery-posts are set facing each other, and united by heavy tie-beams, braced one against the other. This mode of construction gives a very strong and steady battery-frame; but, for dry-crushing purposes, is attended with disadvantages. In the one case known to the Author of the adoption of this type of mill, the conveyor-system used for transferring the pulp was complicated, and had the further disadvantage of being in part actuated by gearing. The presence of grit and dust in these positions renders the use of gearing very objectionable; another objection to this design of battery-frame for dry crushing is the want of sufficient space for the dry kilns.

The effecting of pulverization with a minimum production of slime calls for special attention in leaching-mills, since the rate of filtration in the vats is dependent on the physical character of the ore-pulp. One of the weakest points in the older forms of the stamp-mill, when used to prepare ores for the leaching process,

was the reduction of a large amount of the ore to an impalpable powder. The changes introduced to increase the output have had the further effect of improving its quality. Less dust is present in the pulp produced by the modern forms of stamp-mill than in that produced by the older forms, because the action of the former is more rapid than that of the latter. The ore remains a shorter time in the mortars, and a smaller amount of the crushed product is subjected to injurious pulverization. The mortars are now furnished with screens on both their long sides, while in the older practice the screens were placed on the front only. The configuration of the mortar itself is better adapted for rapid discharge, the dies are set higher, the machine is made stronger and stiffer, so that heavier stamps and higher speeds can be used. The force with which the partially crushed product is driven from the anvils, and the facilities of escape offered to that part of it which is sufficiently crushed, are increased by these changes. Much less, therefore, rolls back on the anvils to be pounded afresh by the descending hammers. Other changes operate to diminish the production of over-crushed pulp, such as the more extended use of rock-breakers, the mineral being served to the batteries in a much smaller form; and the equally extended use of automatic feeders. As a consequence, the stratum of ore interposed between the stamp and its anvil is kept thinner in the modern types of mill, and the wave-like motion of the pulp against the screens is better maintained—a very important matter in a dry mill. By using a heavy stamp, the dash of the pulp against the screens, and, therefore, its chance of escape from further comminution, is increased; but the shattering action on the ore, as compared with that produced by a lighter stamp, is also increased. The advantages seem to lie on the side of a stamp weighing between 950 lbs. and 1,000 lbs., when, as is nearly always the case, the preliminary breaking of the ore is limited to a passage through a rock-breaker set to crush to 1½ inch to 1¾ inch. Whether the practice of breaking the ore to a much smaller size before feeding it into the batteries, and of using light stamps for the final pulverization, would sufficiently better the physical condition of the pulp to justify the increased complexity of the mill is a matter worthy of careful investigation. Experiments with various types of ore have repeatedly shown that finer breaking in the rock-breakers is followed by increased duty from the mill; thus the preliminary breaking of an ore to the size of coarse gravel, as against breaking to the size due to passage through a rock-breaker with jaws set 1¾ inch apart, will increase the output from the

batteries some 15 per cent. or 20 per cent., the other conditions being the same. The introduction of the multiple-jaw breaker has greatly facilitated the preliminary reduction of ores to fine sizes. The lessening of the amount of ore ground to an impalpable powder is effected also by the following method:—A screen of much coarser mesh than that needed for effective chlorination is placed on the mortar, and the resulting pulp is passed through a revolving screen of the required mesh, the coarse particles being returned to the mortar. This simple modification of the usual practice will frequently effect a great improvement in the leaching qualities of the pulp obtained in crushing brittle dust-forming ores. In a test by the Author with an ore of this type, the rate of filtration in the leaching-vats was nearly doubled by the adoption of this expedient. The 24-mesh sieves used on the batteries were replaced by heavy jig-screens having only 6 meshes per lineal inch, the coarse pulp was elevated a few feet above the cam-shaft floor, and passed through a revolving 24-mesh sieve. The tail division of the housing which surrounded this revolving screen terminated in a pointed bin from which the rejected gravel was run into a wagon and returned to the batteries. The evil of over-grinding is sure to be augmented if the means employed for drying the ores are inadequate to the requirements of the mill; the smallest trace of moisture in the ore fed to the batteries suffices to retard the discharge of the pulp and to increase the amount reduced to an impalpable powder. It is an advisable precaution to furnish leaching-mills with dry kilns of a capacity somewhat in excess of their normal requirements. An efficient apparatus for the suction and removal of dust from the upper parts of the mortars should not be omitted, since the most elaborate precautions of tight housings, or packing around the stamps' stems, fail to prevent the escape of ore-dust into the mill, with the attendant ill effects on the health of the attendants and to the working-surfaces of the machinery.

In one or two instances in which a somewhat coarse grade of crushing proved sufficient, roll crushers have been used in Sonora for grinding ores. At Promontorios the weathered ores, proceeding from the upper levels of the mines, were, for a long period, crushed through a pair of rolls 30 inches in diameter by 11 inches wide, and provided with screens having 12 meshes to the lineal inch. These screens were heavy, for use in connection with the jigging plant used at these mines, and were therefore equivalent to a somewhat finer sieve of the type ordinarily used with stamp batteries. As soon, however, as the unaltered sulphide ores of the points below the drainage level were reached, a greater

degree of fineness of crushing became necessary, and for this the single pair of rolls employed proved so inadequate that recourse was had to stamping. For lixiviation, the physical character of the pulp produced by the roll crusher is superior to that produced by the stamp, being more granular, and much more free from dust, and the percolation of liquids through it is therefore more rapid.

In the few modern mills of this type which have been built for leaching works, the crushers are more strongly built, and better adapted to the work required of them, than was the case in the older machines; the rolls are driven at a higher speed, and the reduction of the ores in one pair of rolls, from the size produced by a coarse rock-breaker to the condition of fine meal, is abandoned. Not only is the preliminary breaking carried further than formerly, but the actual crushing is effected through two pairs of rolls. The results obtained have, however, not been entirely satisfactory; in one or two excellently built mills the crushers, when submitted to the test of continuous hard work, have failed to supply the furnaces with the amount of fine meal required of them. The roll crusher, although without a rival as a reducer of ore to small gravel size, has but a limited capacity when used as a fine pulverizer. So that if roll crushers are to be successfully employed for the production of fine meal, for such purposes as those of the leaching process, the principle of graduated reduction in a series of machines must be more thoroughly applied. In view of the wear and tear of the rolls and sieves, it is doubtful whether any cheapening of the operation of crushing would be brought about by substituting rolls for stamps; the advantage to the lixiviation process would be the much improved condition of the crushed ore, both for the chloridizing furnaces and for the filtering vats.

Roasting-Furnaces. — The long reverberatory furnace is, in Northern Mexico, used more generally in connection with the lixiviation process than any other type of roaster. The tendency towards the adoption of mechanical furnaces has, however, increased of late years; the scarcity of labour in the mountainous districts offers a strong incentive to the employment of these labour-saving devices at the mines, the ores of which are susceptible of treatment by their agency. There are, however, in a number of instances, ores unsuitable for this mode of treatment, and the owner has no choice but to use the labour-consuming reverberatory furnace.

The length of the reverberatory furnace to be adopted depends on the amount of sulphur contained in the ore, and, in most cases,

varies between 40 feet and 60 feet. This space is divided into several hearths, usually 10 feet to 12 feet long; a usual type of furnace for an ore moderately charged with sulphides having four hearths each 11 feet long, and for an ore more highly charged with sulphides five hearths each 12 feet long. With ores rich in pyrites a length corresponding to six 12-foot hearths is sometimes employed; the latter may be regarded as the maximum length, and no useful purpose is served by increasing it. The hearth floors are horizontal, that nearest the fire-bridge being the lowest, and each successive one is set about 3 inches higher than that contiguous to it. Occasionally these steps are omitted, the whole hearth lying in one horizontal plane; the omission, however, is not to be recommended, as the steps serve to lessen the mixing of the various ore charges. The furnaces are about 10 feet in width when provided with working doors on one side only, and 12 feet to 12½ feet when furnished with working doors on both sides; the former are much more frequently found in use than the latter.

One of eight furnaces built by the Author at the Yedras mines is shown in Figs. 1, Plate 2. The only ground available for these furnaces was considerably steeper than desirable, and, partly with the view of lessening the amount of excavation needed at the inner ends of the furnaces, the outer ends were set over arched vaults. Into these vaults, the floors of which were highly inclined, the roasted ore charges were dropped in a red-hot condition, and, after cooling, were run into wagons and transferred to various points of the cooling-floor. The vaults were freely supplied with air, and the fumes from the glowing charges were carried off by flues passing under the centre of each furnace and communicating with the dust-chambers. In many ways this mode of discharge proved superior to that of dropping the red-hot charges into wagons and dumping on the cooling-floor; the entry into the works of the dense clouds of chlorine fumes, and of roasted ore dust, which are given off during the discharge, is suppressed, the amount of chlorination which ensues after dropping the charge—the so-called "heap chlorination"—is increased, and the furnace is much more rapidly emptied, as no time is lost in withdrawing one wagon and bringing up another. The further important advantage is obtained that much of the unhealthy cooling-floor work, such as that of sprinkling water on hot ore, is obviated. Where wide furnaces with doors on each side are adopted, this system may with advantage be carried a stage further, by discharging from one side of the furnace for a certain number of hours into one compartment of the vaults, and then from the other side into another compartment; by these

means the pulp can be almost entirely cooled before removal. One reason for the almost exclusive use of the narrow furnace is the fact that the few wider furnaces introduced were still of small dimensions, so that the increase in the number of men required for their manipulations was out of proportion to the increased volume of the ore charge, and the saving in fuel was largely offset by an augmented labour cost. Great reductions in the cost of roasting copper ores have, of late years, been effected in the western part of the United States by the employment of reverberatory furnaces of large dimensions.[1]

In many of the mountainous districts of Northern Mexico the labour supply is very irregular, and work has to be interrupted and resumed in accordance with the fluctuations of this supply. The roasting-furnaces are therefore occasionally shut down and again fired up; since this process of successive cooling and heating, which greatly shortens the life of the arches of the narrow furnaces, is destructive to those of the wide type, the retention, under such conditions, of the smaller furnace seems advisable. In the more settled parts of the country, however, where this influence does not apply, the use of much wider furnaces is practicable, and would materially diminish the cost of roasting. The walls of the furnace up to about 1 foot below the line of the hearths are of brick, or rubble, set in lime mortar; and above that point of brick set in clay mortar; they are thick in order to keep the exterior as cool as possible: the climate renders this precaution indispensable. Fire-brick is used only in the lining of the fire-box and fire-bridge, and the short arch covering them. At Promontorios the fire-box walls and bridge were made of cut blocks of a refractory stone found in the vicinity. The space under the hearths is filled with dry sand or dry ore-tailings, or with fine screened gravel; the use of rubble or débris is avoided as tending to produce uneven settlement. The hearth is paved with red bricks laid on their long edges, and the outer row of each step with bricks laid on end; the hardest bricks, those from the arches of the burning kilns, are selected for the hearths. The bricks are made on sand floors; those used for the hearths and the main arches have therefore to be rubbed down to remove roughness. At the Rosario mines a brick-making machine was comprised in the constructional plant, and its cost was returned many times over in the increased expedition of the work and the better quality of

[1] "Modern Copper Smelting," by Edward Dyer Peters, pp. 445–470. New York, 1895.

the bricks furnished. In the main arches, tiles equal in area to two bricks are used, and the number of joints is thereby halved; the arches so made last as long as those made of ordinary brick. Immediately over the wide low fire-bridge a few holes are left in the arch, through which air, heated by passage through the hollow walls and over the arch of the fire-box, is admitted; for the same purpose apertures communicating with the interior of the first hearth are left in the fire-bridge itself; two sliding doors in the outer wall serve to control the amount of air admitted at these points. As the working doors are never closed whilst the furnace is at work, the atmosphere in its rear and middle parts is highly oxidizing, but that of the first hearth may, unless the above precaution is taken, be at times the reverse of oxidizing; the pitch pine so largely used as fuel in the Sierra, as well as many of the hard woods of the coast, give off, immediately after firing, great volumes of smoky reducing flame.

The dust-chambers between the furnaces and the chimney are frequently too small to be effective; in some mills they are omitted, a short stretch of flue being relied on to collect the ore dust. Where mechanical roasters are used, the furnace gases are passed through a long chamber divided horizontally and vertically by thin partitions, so as to form a serpentine, causing the deposition of dust to take place at the bends. At the Yedras mines the furnace gases were passed through such a chamber, and had further to traverse several hundred feet of spacious flue before reaching the chimney. It would undoubtedly be an improvement to construct the entire length of flue in short stretches, so that the whole could be cleaned from the outside by the hoe. The incessant changes in the direction of the gases would make such a flue a much more effective collector of dust than the ordinary straight one, and a somewhat smaller length might therefore be adopted; the efficiency of this zigzag flue would be increased if several of the sections were made about three times as wide as the average width of the flue, so that the fumes would have to traverse, at certain intervals, zones of slowly-moving current. The height needed for draught, and for discharging the noxious fumes at a safe distance, is generally obtained by running the flue up the side hill, the chimney being merely built high enough to have its top clear of surface currents; the stacks at Promontorios and at Yedras were 6½ feet square inside and 54 feet high.

The allotting of ample space for the cooling-floor—the paved area on which the roasted ore is spread and moistened—cannot be too highly recommended. Where it is either too small, or impro-

perly located with reference to the rest of the works, the operations conducted on it are expensive and tedious. Even where the area assigned to the cooling-floor is ample, and where the facilities for conveying the roasted pulp to and from it are good, these operations call for a large expenditure of manual labour, and, with many types of ore, are unwholesome.

The Leaching Plant.—The operations of leaching are now invariably carried out in circular wooden vats. In the early days of the use of the process rectangular wooden tanks were employed, but the difficulty of making and keeping this form of receptacle perfectly tight led to its abandonment. Three types of vat are made: the ore- or leaching-vats, the precipitating-vats, and the storage-vats. The leaching-vats have to serve as filters, and are provided with false bottoms.

Under normal circumstances, the useful sizes of vats lie between a diameter of 15 feet for use in small mills, and of 25 feet for use in large mills, those with a diameter midway between these limits being very well suited for use in mills capable of treating 50 tons to 60 tons of ore per day. In the event of the construction of very large works these diameters might well be greatly exceeded. The depth of the ore-vats depends, to a certain extent, on the character of the ore, and the degree of fineness to which it is ground. Few ores, even argillaceous ores, have a tendency to form slime, and so hinder filtration, after a thorough roasting, those containing lime being perhaps the worst from this point of view. The other cause of slowness of filtration, the presence of dust in the pulp, is of more frequent occurrence; the metallic constituents of many ores are extremely brittle, and are, during pulverization, reduced to an impalpable powder, even when comparatively coarse screens are used. To guard against possible difficulties in the way of filtration, the ore-vats in the older establishments were made with a depth above the false bottom of only 3½ feet to 4½ feet, but the tendency has always been to increase this depth, and vats with a depth of 5½ feet to 6½ feet are now commonly used. At the same time the height at which these vats are set over their recipients has been increased from about 2 feet to as much as 6 feet, so that the pressure on the surface of the filter is considerably increased. The usual method of discharging the spent ore is to shovel it over the sides of the vats into V-shaped launders. Water is at most of the mines very scarce, and has to be carefully husbanded; these launders are therefore set at a gradient so steep that a very small stream suffices to carry off the tailings. In some cases even this amount

of water cannot be spared and the tailings are shovelled into wagons. Some of the vats built for use in the Russel process are 7 feet and more in depth, and the tailings are removed by sluicing—the best method of removing them if the necessary water is obtainable; the false bottoms of the vats are set horizontal. In this process, ejectors, or other suction appliances, are used to increase the pressure on the surface of the filters, and the use of deep vats is recommended under all circumstances; where sufficient water for sluicing does not exist, the removal of tailings in buckets hoisted by mechanical means is to be recommended; the latter mode is in use at some of the works in which gold ores are treated by the cyanide process. A leaching-vat has been devised by Mr. O. Hofmann in which the false bottom has the form of a blunt funnel, and the spent ores are sluiced through the centre of the vat; the object of this mode of construction is to lessen the quantity of water needed for sluicing. The false bottoms are composed of narrow wooden slats attached to the bottoms of the vats of the perforated boards which rest on these slats, and of the cloth through which the material is filtered. The holes in the perforated boards are about 1¼ inch in diameter, and 3 inches apart from centre to centre. Two holes are bored in the vat below the false bottom, one to serve for the drawing off of the solution, the other for the escape of the air which lodges in this space. Around the edge of the vat some wooden segments are laid over the filter cloth and tightened by wooden wedges inserted at two or three of their joints. The cloth is somewhat larger in diameter than the vat, and the surplus is pressed between the segments and the edge of the vat. Filter-beds consisting of broken slag or stone surmounted by a thin layer of gravel, such as tailings from jigs, have been sometimes used. Such bottoms need be disturbed but rarely, and offer other advantages; but they have the disadvantage of taking up much more of the useful depth of the vat than the board- and cloth-filter; where the removal of tailings is to be done by sluicing, the use of such beds is of course inadmissible. A convenient size of vat for the precipitation of the silver sulphide is between 12 feet and 13 feet in diameter by 10 feet deep.

The timber commonly employed on the coast belt for the construction of vats is a variety of cypress named sabina; it is very durable, and admirably adapted for such purposes. Cedar is readily and cheaply obtainable at many points, and is equally suitable. Californian redwood is also suitable for these purposes; at the Rosario mines, which were connected with the seaboard by a wagon road, the vat staves and vat bottoms of this material,

prepared by machinery, were shipped from San Francisco. In works situated in the mountains, the vats have to be made of the pine of the locality, the only timber available.

In modern lixiviation works the vats are usually placed on timber trestles resting on low walls. At mines where long timber is unobtainable, the supporting walls are raised a few feet above the ground, and the joists which receive the vats are placed directly on them; in such localities each line of vats is covered by a low shed supported on posts of native hard woods. At the pioneer lixiviation establishments in Sonora, the tops of the ore-vats stood only 2 inches or 3 inches above the surface of the ground, and the roasted ore was wheeled to their edge and tipped into them. This mode of erection, which is open to several objections, has long been discontinued. The natural and the most convenient arrangement of the plant is to set the vats in tiers, Figs. 2, Plate 2, the ore- or leaching-vats at the top, and the precipitating-vats and storage-vats following in order. Among the more important of the subsidiary portions of the plant are the means employed for elevating and conveying the solution of calcium hyposulphite. The solution attacks brass and gun-metal, but has no effect on hard antimonial lead. On cast-iron surfaces, with which it is merely brought in contact, as in pipes of that metal, the attack is so very slow that it may, in practice, be disregarded. Under certain conditions, however, the rate of attack becomes noticeable; for instance, the friction between the piston and cylinder of a double-action pump renders the rate of attack sufficiently rapid to make the use of such apparatus inadvisable. With this condition modified, as in the case of a cast-iron plunger in rubbing contact with a soft packing, the rate of attack is again practically unimportant. But another characteristic of the solution has to be taken into account; on all iron surfaces over which the solution moves slowly, or is sometimes permitted to rest, a firmly adhering scale of gypsum is formed, and the rate of deposition is sufficiently rapid to enforce frequent dismantling and cleansing of the apparatus. Where, however, the conditions for such deposition are unfavourable, for instance, where the current is rapid and long horizontal waterways do not occur, the difficulties from this source are reduced to a minimum; for this reason the centrifugal pump, if wholly of cast-iron, is an efficient apparatus for the raising of this liquid. In the erection of the pump, the discharge-pipe is set vertical, and has no turns or elbows, but is united by a flange to the bottom of a large wooden trough, and the pump is set low so that only a short suction-pipe is required; witn these precautions pumps of this type

work well for many years, and give but little trouble. If very deep vats are used, it may be necessary to use two centrifugal pumps, one delivering to the other. For distributing the solution, the use of iron pipes is altogether eschewed, and wooden launders used; the connection between the vat and the launders is made by stout rubber hose, 1½ inch in diameter, attached to short lead tubes inserted in the bottoms. No metallic stopcocks or valves are used; the flow of solution is sometimes regulated by screw clamps placed over the hose, but oftener by tapering wooden plugs inserted in the extremities. Gypsum is deposited to a small extent on wooden surfaces, but is easily detachable from them; the only part of the plant where its presence is of any consequence is in the space beneath the false bottoms of the leaching-vats, and this is cleaned every two or three months. The holes of the false bottoms are always burnt out after being drilled, and no deposit forms in them. The filter-cloths are frequently washed, and last several months. For the manufacture of the calcium sulphide solution a species of churn, with cast-iron bottom and sheet-iron sides, is used, a convenient size being 6 feet in diameter by 9 feet deep; a discarded amalgamation-pan is sometimes used for this purpose. This solution has no effect on iron, and is conveyed in ordinary gas-pipe; it must be stored in iron vessels.

The Manipulation of the Process.

Chloridizing-Roasting of the, Ore.—The results obtained by the use of the process depend very largely on the way in which the operation of roasting is carried out. When it is well conducted the close and economical extraction of the silver, by the hydro-metallurgical operation which follows, is practically assured. On the first employment of the lixiviation process, the roasting of the ore was accomplished in short single-hearth reverberatory furnaces, which did not greatly differ in form from the old types of calciner used with copper ores. Their use has now been entirely abandoned in favour of the long multiple-hearth reverberatory furnace, or, of furnaces in which the ore is stirred by machinery. A number of advantages attended the change from the single-hearth to the multiple-hearth furnace; the work is more expeditiously and cheaply accomplished; the roasting operation is a continuous instead of an intermittent one, because the necessity of allowing an interval for cooling between the withdrawal of a roasted charge and the admission of a raw one is dispensed with.

The mode of treating an ore in a long reverberatory furnace may

be regarded as typical of that employed in any form of furnace, and the same remark applies to the various chemical reactions which take place during the treatment. For this reason the operation of roasting is here described as carried out in this form of furnace. For ores which present no abnormal difficulty, and for which the process has been largely used, such as those in which iron pyrites, with a small admixture of copper pyrites, fahl ore, or galena, are the chief metallic components, and the matrix is for the most part quartz, the manipulations may be briefly described as follows: A charge of ore, crushed to a fineness due to a passage through a sieve, with twenty-four to thirty holes per lineal inch, and to which between 3 per cent. and 6 per cent. of common salt has been added, is run from the hopper into the hearth furthest removed from the fire, say the fifth, and is at once spread out with the rabble. The weight taken for a charge may be 16 lbs. to 18 lbs. for each square foot of the area of the hearth. With an ore of this type the charge will not remain in each hearth longer than one or one and a half hour; in the fifth hearth it will receive scarcely any raking or stirring, since at this stage the ore runs like quicksand on the least touch with the rake or rabble. At the end of this period the charge is advanced to the contiguous hearth, all the charges in the furnace being simultaneously advanced one stage. The arches of the furnace, with the exception of the first, are at all points in close proximity to the sole of the furnace, so that the surface of the ore is exposed to a stream of red-hot air charged with the products of the combustion of sulphur and of the decomposition of sodium chloride, and the draught is so regulated that this current of hot gases rolls slowly along the surface of the charges. Under these conditions a portion of the sulphur of the pyrites ignites soon after the removal of the charge to the fourth hearth, and volatilizes as sulphurous acid; the mass is stirred as often as the blue flame of the burning sulphur disappears, in order to expose fresh surfaces to the action of the air. This combustion of one part of the sulphur of the pyrites affords sufficient heat to bring the charge to the incandescent condition, in which it is passed on to the third hearth, where the circumstances are highly favourable to the formation of sulphates, a very important part of the operation. The charge itself is in a condition of readiness. It is in a dull-red glow, and at the same time has but little tendency to sinter or form hard balls through the partial fusion of its sulphides, the decomposition of the latter being sufficiently advanced to remove this tendency. The atmosphere in the interior of the hearth is at the right temperature and highly oxidizing, as the amount of air admitted at all

stages of the process is much in excess of that needed for the combustion of the sulphur. The gas evolved from the ore-charge at this stage is sulphurous acid, intermixed with a large amount of chlorine and some sulphuric anhyride proceeding from the advanced charges in the two lower hearths. The presence of the two last-named gases increases and quickens the reactions in the third hearth. In this hearth the charge becomes coherent and begins to swell. About an hour after its entry signs of the beginning of chlorination are perceptible. Chemical tests show that this action has been in progress from the first entry of the ore into the furnace, but up to this point it has not been manifest to the eye. The reactions in the third hearth are therefore the combustion of sulphur with evolution of sulphurous acid, the formation of sulphates, and incipient chlorination. In the second hearth the charge receives much more stirring than hitherto, and its chlorination is much advanced. In the finishing-hearth the temperature, immediately after the dropping of a spent charge, is that of a dull cherry-redness. Since this temperature suffices, with most classes of ore, to bring about the mutual decomposition of the sodium chloride and the various sulphates formed in the earlier stages of the roasting, the charge, on being exposed to it, presents all the phenomena which attend active chlorination. It greatly increases in volume, becomes slightly pasty, and gives off, at all surfaces exposed to the air, dense volumes of chlorine intermixed with small amounts of hydrochloric- and sulphuric-acid gases. On the first use of the process in Sonora, steam was admitted over the fire-bridge for the purpose of increasing the formation of hydrochloric-acid gas, but no improved results followed from this practice, and it was abandoned. With the same object in view, green wood was sometimes used as fuel, but its use also ceased. During the period of very active chlorination the fire on the grate is kept low, and air is admitted to the full extent of the apertures provided for the purpose in the arch and the fire-bridge; that the interior of the distant hearths may not be chilled by this large introduction of air, the advantage of previously heating it, by passing it through the walls and over the arch of the fire-box, is manifest. The usual practice of admitting air through the doorways of the ash-pit and the fire-box is very wasteful of fuel. The chemical reactions in progress at this stage are accompanied by a great evolution of heat, by which, supplemented in other parts of the furnace by that arising from the combustion of sulphur, the temperature over the great length of the furnace is practically maintained. When, by the lessened evolution of chlorine, the change of colour of the ore-

pulp, and the general toning down of the vigour of the reactions, the operation is judged to be nearing completion, the supply of air is reduced and a few sticks of wood are thrown on the fire-bars. Samples are frequently drawn from the charge, cooled quickly on an iron plate, and carefully examined. Since these samples are daily tested in the laboratory the physical characteristics of properly roasted pulp soon become familiar, and the exact moment at which any charge is dropped is determined from the simple inspection of these samples.

Many of the difficulties which surrounded the roasting of several classes of ore in the single-hearth furnace have been removed by the use of the long furnace. Ores, for instance, containing a large quantity of easily fusible sulphides could not be treated in the short furnace without the formation of balls from the sintering, or partial fusion, of these substances. And, since the silver contained in these balls could not be extracted by the solutions, it became necessary, either to break them up on the hearth of the furnace with heavy tools, or to pass the whole of the roasted ore through sieves, to return the coarse part to the grinding machinery, and to re-roast it with raw ore; neither of the remedies was efficient, and both were expensive. Difficulties from this source are rare with the long furnace, the sulphides lose much of their sulphur in the cooler hearths, and show little or no disposition to sinter on reaching the hotter hearths. The use of the long furnace is especially advantageous in the treatment of ores rich in arsenic, the sulphide of which volatilizes at a low temperature, and the arsenious and sulphurous acids resulting from its dissolution are carried off by the draught. If, however, during the first stages of the roasting the temperature is increased, this desired volatilization is checked, the formation of arsenates takes its place, and the presence of these salts retards the roasting in its later stages. Every effort is therefore made to eliminate all the arsenic possible in the cold stages of the roasting, and the chief means to this end, the maintenance of a low temperature, is automatically provided in the long furnace; occasional carelessness in the matter of firing cannot, owing to the distance of the final hearths from the fire-grate, do away with this condition.

The gangue, or matrix, associated with the ore, plays an important part in the roasting process. Owing to its being less brittle than the ore proper, it issues from the grinding machinery in a much coarser form than the latter, varying in size—according to the sieves employed—between coarse sand and fine meal. The presence in the ore pulp of large amounts of this coarsely crushed material renders it porous, open, and permeable to the furnace

gases. This fact is often disregarded in small establishments, where the desire to keep the yield of the ore in silver at the highest attainable point causes the work on the breaking-floors to be carried much too far and the gangue as far as possible eliminated, the result being that a heavy, non-porous mass of metallic sulphides is served to the furnaces. The useful effect of the gangue is a purely mechanical one, and in the same category may be placed the power possessed by some of its varieties of promoting and influencing reaction by mere contact. The quartz and the acid silicates of the gangue, however, play an important part in the chemistry of the process, since the temperature employed in the lower hearths of the furnace suffices to call into play the power possessed by silica of displacing sulphuric acid from the metallic sulphates present in the charge.

The amount of salt needed for the treatment of the different varieties of ores varies between somewhat wide limits; the quantity, where reverberatory furnaces are used, may be said to lie between 3 per cent. and 7 per cent. of the dry weight of the ore treated. In practice, in dealing with an ore for the first time, or in case of a change in the ore furnished by a known ore body, the proportion is roughly arrived at by roasting a few pounds of the ore in an experimental furnace; a proportion of salt slightly in excess of that indicated by the experiments is then employed on the large scale, and is gradually reduced under the guidance of the laboratory tests of the roasted product. In many localities the high price of salt enforces the strictest economy in its use, and in some of such cases it may be advantageous to crush this reagent with the ore, since the perfect admixture produced by this method permits the use of the minimum quantity. The great objection to this mode of introducing the salt is that the duty of the stamping machinery is thereby lowered, often seriously. The salt, after leaving the drying apparatus, reabsorbs moisture with great facility, and damps the ore with which it is brought in contact. For this reason the prevailing practice is to crush the salt separately and to serve the amount needed to the ore in the furnace hopper.

The determination of the loss of silver during the chloridizing roasting of ores offers considerable difficulty. In laboratory experiments, where elaborate precautions against the mechanical loss of part of the mineral can be introduced, the actual loss by volatilization, under a given set of conditions, can be ascertained; but the value of the results is diminished by the uncertainty as to whether all the conditions of the operation on the large scale are reproduced in these trials in miniature. In tests on the working

scale this loss is approximately estimated in the following manner. A parcel of between 50 tons and 100 tons of ore is crushed to the required degree of fineness, and roasted with the least possible loss of dust. The draught of the furnace in which the experiment is carried out is kept sluggish during the whole period of roasting, and is almost entirely cut off at the moments of running in and advancing the different charges. With the same object in view, the end charges—those nearest the flue—are not rabbled during the experiment. The crushed unroasted ore, the roasted product, and the contents of the dust-chamber attached to the furnace are carefully weighed, sampled, and assayed. The difference between the silver-content of the raw ore served to the furnace and that of the two products obtained from the furnace and its settling-chamber is reckoned as furnace loss. It is expressed in terms per cent. of the silver contained in the unroasted ore. A rough balancing of the account takes place in this mode of evaluating the furnace loss, for, on the one side, no cognizance is taken of the small amount of condensed fume which is recoverable from the colder parts of the flues, and on the other side, the firing and other manipulations of the roasting receive a more than ordinary measure of attention during this experimental work. The routine work of the assay office comprises daily assays of the raw pulp served to the furnaces and of the roasted pulp obtained from them. If the difference of weight between the raw and roasted ore is known from the working tests described, these daily assays give a fair clue to the extent of the furnace loss of silver. For example, if at a given date the yields on assay of the unroasted and roasted pulps are respectively 23 ozs. and 21·8 ozs. of silver per ton, and the loss of weight sustained by the ore during roasting is 4 per cent., the furnace loss of silver will be about 9 per cent.

As a rule, the loss of silver by volatilization is least when the salt is added to the ore at the beginning of the roasting; but in a few cases this loss is reduced when a prolonged oxidizing roasting of the ore precedes the addition of the salt.[1] With many types of argentiferous ore the amount of silver lost by volatilization is much less when the salt needed for chloridizing is added at the start than when it is added at a late stage of the operation of roasting, because the salt undergoes slow decomposition during the whole period of roasting. Part of its chlorine performs useful

[1] The time at which the salt should be added to cause the least loss of precious metal by volatilization is discussed by Professor Christy in a Paper on "The Losses in Roasting Gold Ores, and the Volatility of Gold," Transactions of the American Institute of Mining Engineers, vol. xvii., p. 3.

work in chloridizing the metals present in the ore, and part is lost as chloride of sulphur, so that when the stage of the operation is reached at which the temperature is highest, the energy of the reagent as a producer of chlorine is sensibly lowered, and the volume of chlorine to which the finely divided silver compound is exposed is much reduced.

The main influences which tend to increase the loss of silver during the chloridizing roasting of its ores, are, the employment of too high a temperature, the undue prolongation of the roasting operation, and the excessive generation of chlorine, in other words, the addition of the salt in more than the requisite amount, or, at an unsuitable period of the operation. The effect, however, of using much more salt in the working of some varieties of automatic furnaces than is usual in the hand-worked reverberatory furnaces, is minimized by the great shortening of the time of roasting. These exciting causes are only to a partial extent under the control of the operator, a sufficient degree of heat, of duration of the roasting period, and of generation of chlorine, to effect the chloridization of the silver sulphide contained in the ore, must be employed. The effect, however, of such changes of the conditions as are within reach in actual work may be very great, and is particularly noticeable with respect to changes in the temperature employed in roasting. In the experimental roasting, on the working scale, of three parcels of the same ore, the effect of roasting at temperatures corresponding to cherry red, red and dull red heats, was carefully determined; the furnace losses, beginning with the ore roasted in the greatest heat, were, respectively, 15·9 per cent., 13·7 per cent., and 11·6 per cent. of the silver contained in the unroasted ore. Nearly half the loss occurred in the final chloridizing stage; in a further lot of the same ore, which was discharged before chloridization was complete, the roasting loss was only 6·3 per cent. It cannot be expected that the care bestowed on the exact management of the temperature, in such experimental work as that referred to, will be given to the continuous operation, certain safeguards against the occurrence of over-firing, or its consequences, are therefore provided in the construction of the furnace; the area of the fire-grate is limited as nearly as may be to the working requirements, the arch over the finishing hearth is set high so that the flame does not touch the ore, the fire-bridge is prolonged; where a very delicate ore is worked, it would doubtless be advantageous to further prolong the bridge, and, in fact, to interpose a small chamber between the roasting hearth and the fire-place.

The necessity of carrying out the operation of roasting at the lowest possible temperature is enhanced by the fact that but little of the silver volatilized is recoverable by cheap and readily available means of condensation. Such part as is saved is found in the deposits and accretions formed on the floors, walls and arches of the colder parts of the flues; these deposits consist mostly of the chlorides and sulphates of the base metals associated with some fine ore dust; assays obtained from them frequently give yields of silver between two and three times greater than those of the ore treated in the furnaces. The material is deposited in a lightly coherent, flocculent form; it is exceedingly light, so that during the cleaning of the flues it is necessary to partially cut off the draught; in fact, the flues should be cleaned from outside, and the draught entirely cut off during the operation. The presence of a deposit of this fume on the arches and walls appears to favour the precipitation of fresh coatings.

The use of furnaces in which the stirring of the ore is performed by mechanism, actuated by steam or water-power, has not become general in the north-western States of Mexico; in several of the mining districts the ores obtained are of the highly sulphuretted type, and in many others the absence of good facilities of transport makes the first cost of these motor-furnaces very high.

The use of roasting furnaces, however, in which the manipulation of the ore is effected by machinery, such as the White-Howell, the Bruckner, the Hyde-Bruckner, and the Stetefeldt furnaces, offers great advantages over that of hand-worked furnaces.[1] The cost of operation is much lower, due mostly to the great saving of manual labour; in remote localities where the supply of labour is intermittent and scarce, the lessening of the cost of this item does not, however, represent the full benefit derived from the use of machinery; the large number of men which would otherwise be needed for the work of roasting is available for other purposes, and this is often a more important matter than the saving of wages. Great economy of fuel also results from the employment of some of the varieties of the motor-furnaces. In parts of Sonora, where the hard wood used as fuel costs as much as $8 per cord of 128 cubic feet, it is difficult to over-estimate this advantage. The rapidity of the action of the motor-furnaces probably also causes a further advantage, in the shape of a diminution of the amount of silver volatilized and lost during roasting. This loss is, to a certain

[1] See also Transactions of the American Institute of Mining Engineers, vol. xiv. p. 576.

extent, a function of the time employed in roasting; if the other conditions which affect this loss, more particularly that of the temperature employed, remain the same, then the shorter the period during which the ore is exposed to the action of heated air and chlorine the less will be the loss; the qualification as to the maintenance of the other conditions is important.

The difficulties that occur with motor-furnaces are, in most cases, due to the presence in the ore of a large amount of sulphur, or of sulphur and arsenic. Since their expulsion is most conveniently carried out by roasting the ore in lump form, the mode of burning in heaps has been experimented with in some few instances. But such additions to the routine of crushing, chloridizing, and leaching do not find favour. The loss of silver sulphate in periods of rain or snow is a great objection to the burning of silver ores in heaps, but the objection does not hold if the operation is carried out in stalls, as these can be easily and cheaply roofed. A considerable proportion of the cost of the extra handling involved in the method is compensated by the lessened cost of crushing, as the burning leaves the ore very friable. The loss of silver during the burning in lump form is, in most cases, small, and the consequent loss in the form of sulphate of silver leached out by rain is easily avoidable; the ore submitted to the action of chloridizing roasting is transferred from the highly sulphuretted, refractory class, to the partially oxidized, or free-roasting class; the operation of chloridizing roasting, that in which the greatest loss of silver is incurred, is therefore rendered much less delicate and more rapid.

The roasted ore is slightly moistened before being trammed to the leaching-vats; it is cooled on a paved area, sprinkled with water from a hose, turned over and mixed with the shovel, and heaped up at the side of the track which passes over the vats. These manipulations are costly, since they require hand-labour, and they are rendered disagreeable and unhealthy by the ore dust which arises during their progress. Improvements in the arrangements of the cooling-floor, with the view of making the work upon it less dependent on hand-labour, and less productive of loss of ore dust, have not kept pace with those effected in the other departments of lixiviation works. On the one hand, the grading of a large space out of the side hill and its roofing are expensive pieces of work; on the other hand, the roasted ore pulp, after being wetted, can neither be raised in an ordinary elevator nor run out of a bin of ordinary inclination; nor, if it contains copper, can it be manipulated in any apparatus constructed of iron. As

long, however, as the pulp remains dry, its handling and transport present no difficulty, and it certainly seems desirable that the labour-saving expedients employed in the crushing-mill, such as tipping into bins or vaults, filling into wagons from spouts, moving by horizontal conveyors, or raising in bucket-elevators, should be more freely used in this part of the work. The dropping of the red-hot charges from the roasting-furnaces into a line of vaults, open to the air at one extremity, and communicating with capacious dust-chambers, and the main flues at the other extremity, is merely one step in the direction of utilizing such expedients. A further step would be gained by providing a second line of cooling-vaults, also communicating with the air and with the flues, and filled by wagons which draw from the spouts of the first line of vaults. By such an arrangement the furnaces may be kept clear of the roasted product, and the latter cooled with very little expenditure of labour, and one common cause of the production of dust, the wetting of the roasted pulp before it is quite cold, would be removed. The wetting of ore whilst warm affects injuriously the subsequent extraction of the silver.

The wetting of the cold pulp is most commodiously effected on a narrow strip of ground, bounded on one long side by the railway from the cooling-vaults, and on the other by that leading to and passing over the leaching-vats. The wagons of the latter are filled with the shovel from the ground, but a cheaper mode would be to fill them from a continuous bin by means of the hoe. Moist pulp is slowly destructive of brickwork, so that the bin may be made of wood fastened with trenails of the same material. Certain types of roasted ores are benefited by remaining two or three days in the moist condition. With ores, for instance, containing copper, any silver sulphide which may have escaped decomposition during the roasting is exposed to the joint action of copper chloride, air, and moisture, and is thereby converted into silver chloride. The result of this reaction is an increased extraction of silver by the hyposulphite solution. On the other hand, some ores receive no such benefit, the laboratory tests made on moistened pulp showing no appreciable increase in the percentage of silver soluble in hyposulphites over that contained in the dry pulp; and in such cases the method of charging the vats with dry pulp appears to be worthy of trial.

Leaching and Precipitation.—The roasted pulp, after being placed in the vats, is leached with cold water until the various salts of the base metals, soluble in that menstruum, are removed. The sodium sulphate, resulting from the decomposition of the common salt, and

the undecomposed excess of the latter, are also dissolved out. The duration of the operation varies according to the greater or less difficulty offered by the column of ore to the passage of liquids, the amount of soluble salts present, and the quantity of water available. With vats holding 80 tons to 100 tons of ore, it lies between the extremes of eighteen hours and seventy-two hours. The washing is continued until the addition of a few drops of calcium sulphide to a sample of the filtrate produces no precipitate or even turbidity. This first leaching cannot be too thorough, since the salts not removed by it enter into and greatly injure the solution employed in the second leaching. It unfortunately happens that in some of the mines in the littoral and in the foot-hills of the Sierra, the supply of water during parts of the year is inadequate, and either the leaching with water has to stop short of the point of the complete removal of soluble impurities, or the treatment of ore in the dry season has to be curtailed. In such cases the latter alternative should be adopted.

On the first application of the wash-water, care is taken to obviate, as far as possible, the formation of a strong solution of common salt, since silver chloride is soluble in such solution. With this view the water is at first introduced at the bottom of the vat, underneath the filtering medium, and allowed to make its way upward through the mass of roasted ore. As soon as the vat is full, the water is run out at the bottom of the vat and fresh water run in at the top. By this means concentration of the solution in the lower part of the vat is avoided, and such of it as may have begun in the upper part is rapidly diluted. This precaution does not entirely prevent the solving of a small amount of silver chloride in brine, and the first portion of the discharge is therefore run into a special vat and treated with calcium sulphide. When the quantity of copper contained in the ore is sufficient, the base metal water is passed through a series of launders filled with scrap-iron.

The maintenance of the solvent employed in normal condition, as to strength and freedom from impurity, requires frequent and careful attention. The cold dilute solution of calcium hyposulphite enters the leaching-vat through short pieces of hose attached to the main distributing launder. A convenient arrangement is to set the top of this launder flush with the tops of the vats and to pass the rubber tubes through holes bored in the sides of each a few inches from the top; the tubes, 2 inches in diameter, project a short distance into the vats. The solution in the distributing launder is automatically maintained at a constant level, and communica-

tion with any of the leaching-vats is cut off by hanging up the projecting extremity of its supply hose. The operation of leaching is, at first, carried on as rapidly as possible, the discharge orifice below the false bottom being kept fully open. When the tests show that the amount of silver taken up is much reduced, the volume of solution passed through the ore may be lessened. With certain varieties of ore, however, time is always saved by circulating a large quantity of solution during the whole period of leaching, even when samples of the solution, after traversing the ore, yield comparatively little silver. With ores of argentiferous blende, for instance, especially if a little copper is also present, the duration of the leaching operation is considerably shortened by passing through the ore a volume of solution largely in excess of that apparently required. In order, therefore, that the lixiviation may not be unduly prolonged, on the one hand, or solution unnecessarily circulated on the other, it is advisable, from time to time, to work two or three vatfuls of ore experimentally, and to note the volume of solution circulated, the time employed, and the assay of the spent ore or tailings.

When a considerable percentage of lead, or copper, is contained in an ore treated by this process it is advisable to work with a dilute leaching solution, and to circulate, during the whole period of leaching, as large a volume as practicable of this dilute solution. The use of a solution containing between ten parts and twelve parts of the hyposulphite salt to a thousand parts of water is in every way preferable to that of more concentrated solutions. The climate in many of the localities in which the process is used is extremely dry, and the evaporation from the surfaces of the receptacles is so great that, unless this matter receives frequent attention, a much higher degree of concentration of the leaching solution takes place than is at all desirable. These dilute solutions act on the silver salts contained in the ore in preference to the lead salts; the former may be extracted down to the remunerative point before any serious solving of the latter takes place. The greater part of the silver contained in a vatful of roasted ore is extracted in the first period of the leaching operation. This is known as the period of sweet solution, because the solution of silver chloride in hyposulphite solutions is sweet to the taste. The duration of this period is dependent on the richness of the ore in silver, and on the rapidity of the filtration; with a vat holding, say, 80 tons of 25-oz. ore, offering no abnormal resistance to filtration, this period may last between eight hours and twelve hours. The precipitate yielded during the sweet

solution period, even when the ores treated contain a considerable amount of lead or copper, is very rich in silver; dried, and melted in crucibles with a little scrap-iron and borax, it furnishes bars yielding usually about 80 per cent. of silver. On the other hand, the precipitate obtained from base ores, during the remaining period of the leaching operations, is poor in silver; a common yield of the dried precipitate from the final stage of treating impure ores is between 2 per cent. and 3 per cent. of the metal. The hyposulphite solution acts first on the silver salts contained in the roasted pulp, and, when these are almost removed, extends its action to the other salts—notably those of lead and copper—contained in the mass. The greater the degree of concentration of the hyposulphite solution, and the longer the duration of the leaching operation, the greater will be the amount of base metal extracted with the silver. The expediency, when base ores are treated, of employing dilute solutions, and of leaching as rapidly as possible, is therefore apparent. When these two conditions are observed, ores containing considerable percentages of lead and copper are treated with an expenditure on the chemicals of between 60 cents and 80 cents per ton, and furnish a precipitate yielding from 15 per cent. upwards of silver. The spent ore, or tailings, contains usually between 5 per cent. and 8 per cent. of the silver contained in the roasted pulp when ores of less value than 30 ounces per ton are treated; the loss on richer ores is somewhat less. It may be added, that at mines in which the refining of the sulphides obtained from the lixiviation process is attended with difficulty and expense, the silver solution from the sweet period of leaching is precipitated in one set of vats, and that from the finishing period in another set of vats; the precipitate from the former is submitted to the refining operation, and that from the latter is sold as a rich argentiferous lead-copper product.

The silver solution passes to the precipitating-vats through a launder, and has stirred into it a strong solution of calcium-sulphide. During the progress of the stirring, samples of the contents of the vat are frequently tested, and, as long as the addition of a drop of calcium-sulphide causes a tangible precipitate, more of that reagent has to be added. When, on the other side, the addition of a drop of silver solution causes a precipitate, excess of calcium-sulphide is present, and more silver solution has to be run in. As soon as the proper point is reached, the precipitate is allowed to settle and the supernatant liquid is run into the stock-solution of hyposulphite. It is to be particularly noted that the

decanting of this liquid as long as any excess of calcium-sulphide is contained in it must be carefully avoided, since the effect of this would be to convert into sulphide the silver chloride already dissolved in the leaching-vats, and to precipitate it in the ore-mass. As a safeguard against such an occurrence the solution is always brought to the safe side of the neutral point; in practice, therefore, the supernatant solution, and consequently the whole stock of working solution, is caused to retain a slight excess of silver solution; it is at the exact point desired when the addition of a drop of calcium-sulphide causes, after a short interval, a thin bluish white film or cloud technically known as the smoke. An excess of the precipitating reagent in the solution is accompanied by unmistakable signs; the liquid becomes milky from the presence of free sulphur, and, if the excess of reagent is at all considerable, the sulphides will not settle but begin to dissolve, and sulphuretted hydrogen is given off. In most mills the operation of leaching and precipitation is attended to by labourers under the supervision of expert foremen. It has often been proposed to carry out the beating and mixing of the liquids in the precipitating-vats with the aid of machinery, but in mills of small or medium capacity this scarcely seems to be needed. During the considerable period needed for filling a vat hardly any attention is given to it, the silver solution and the precipitant are run in simultaneously, and are roughly mixed by turning the stream of the latter into the former and allowing them to fall together; it is only at the end of the operation that stirring by hand and the exact adjustment of the solutions are effected; one man on each shift attends to this and to the leaching work, in mills treating between 40 tons to 50 tons of ore per day.

The contents of the vat are allowed to stand until the precipitate is quite settled, and the supernatant calcium-hyposulphite is then run off to the storage vats. The aperture through which the solution escapes is between 1½ foot and 2 feet above the bottom of the vat, and to prevent the carrying off of particles of precipitate by a too rapid current, the following arrangement is used. A piece of lead tubing is fitted to the orifice, and to it is attached, inside the vat, a piece of rubber hose of length sufficient to reach the top of the vat at about its centre line; two pieces of wood are clamped to the upper extremity of the hose so that it floats in the solution with its mouth slightly immersed. Through this floating discharge the current escapes without causing any appreciable suction on the precipitate lodged in the bottom of the vat; when not in use the hose and its attached

float are hung on one side of the vat. The strong silver solution from ore in the earlier stage of leaching yields a heavy precipitate which settles rapidly, whereas that proceeding from nearly spent ore is light and settles very slowly; it is, for this reason, advisable to provide an ample volume of precipitating receptacle so that abundant time may be allowed for settling. Some of the older mills were insufficiently equipped in this respect, and a little fine low-grade precipitate was carried off with the solution and arrested at the surface of the ore in the leaching-vats; before shovelling out the tailings a thin layer was raked off and set aside for retreatment.

The great cause of the weakening of the working solution is the oxidizing action of the atmosphere, the contained calcium hyposulphite being converted into gypsum. As long as leaching operations are uninterruptedly carried on, this loss of hyposulphite is compensated—generally more than compensated—by the fresh supplies which are always being formed in the precipitating-vats. But, if active work is suspended, the deterioration of the solution is rapid; a stoppage of work for about ten days greatly impairs its efficacy, and one of a month's duration may render it useless. One of the first requisites, therefore, for the maintenance of the solution in proper condition is continuity of the leaching operations. This requisite is generally upheld without difficulty, since the working of but a small part of the total plant suffices to preserve the solution for a long period; a total cessation of work is rarely called for. The use of a number of vats of moderate size—as against that of one or two very large ones—favours the maintenance of the condition, referred to above, of constancy of regeneration of hyposulphite.

The calcium sulphide employed for precipitating the silver always contains some calcium hyposulphite, which partly accounts for the increase in the volume of the stock of solvent. But the main source of the fresh supplies of calcium hyposulphite which are formed in the precipitating-vats is the double metathesis which takes place between the argentic and other hyposulphites of the silver solution, and the calcium sulphide of the precipitating solution. It follows, therefore, that the higher the degree of concentration of these two solutions, the higher will be that of the regenerated hyposulphite. For this reason it is usual, when ores comparatively free from lead are treated, to make the precipitating solution as strong as practicable; flowers of sulphur and caustic lime are boiled together with such an addition of water that the resulting solution of calcium polysulphide marks 8° to 10°

Baumé. It was formerly customary to use a much weaker solution of calcium sulphide for precipitation, a strength of about 5° Baumé being considered sufficient. With ores rich in silver, and thoroughly well roasted, the consumption of calcium sulphide is sufficiently great to bring about the regeneration of large amounts of calcium hyposulphite, and the stock-solution of the latter is maintained in excellent condition. But, when ores poor in silver and of unfavourable character are treated, the reverse is the case. If, under such conditions, the calcium sulphide is applied in a dilute solution, the fresh supplies of hyposulphite are in too attenuated a form to uphold the strength of the stock-solution. For the purpose, therefore, of being independent of fluctuations in the class of ore submitted to treatment, the practice grew up of employing, under most circumstances, a fairly concentrated solution of the precipitating reagent; the reasons for modifying the practice when considerable amounts of lead, or sometimes of lead and copper, are present in the ore, have already been stated.

The efficacy, as a precipitant, of a freshly prepared solution of calcium sulphide is much greater than that of one which has been some time in stock, since the oxidation of this sulphide into calcium hyposulphite—and finally into calcium sulphate—is always in progress. For this reason it is advisable to limit the size of the apparatus used for the manufacture of the reagent to the approximate requirements of the works, and to make a fresh supply daily. The same necessity of having a freshly prepared article holds good with respect to the burnt lime used in making the calcium sulphide. As the difficulties of transport during the rainy season are great, it is usual to house a large stock of quicklime before the rains set in, where such a course is practicable; it is, however, better to accumulate a stock of limestone and to burn it, as required, on the spot. A considerable portion of the limestone burnt in the usual manner is not converted into quicklime, but remains as undecomposed carbonate. Since in the manufacture of calcium sulphide caustic lime only is of use, the undecomposed portion of the burnt lime remains as a waste product. This, after being washed, still retains solution of calcium sulphide; it is spread out and exposed to the air until the latter salt is converted into calcium hyposulphite, after which it is heaped under sheds and kept for use. At such times as the stock-solution needs strengthening, a layer of this substance is placed in a vat, and its contained salt dissolved and added to the solution. Whenever it becomes necessary to supplement these methods of maintaining the strength of the stock-solution, sodium hyposulphite is added

as required. A stock of commercial sodium hyposulphite is always kept in store for this purpose: under normal conditions of work its use is seldom necessary; it is advisable to have this salt packed in metal-lined boxes, as it slowly oxidizes on exposure to air. A stock-solution of sodium hyposulphite is much more conveniently prepared than one of calcium hyposulphite: operations at new works are therefore begun with the first-named solution, and the same remark applies to the restoration of a stock-solution that may be accidentally lost or destroyed; the strength used is 12 parts to 15 parts of the crystallized commercial salt to 1,000 parts of water, both by weight, for comparatively pure ores, and 10 parts to 12 parts per 1,000 for base ores; as the precipitating medium employed is calcium sulphide, a stock-solution of sodium hyposulphite is gradually replaced by one of the corresponding calcium salt.

The lower part of the ore in the leaching-vats retains, after being washed, a large amount of water. The first portion of hyposulphite solution which is admitted to the wet mass becomes greatly diluted, and, in order that the whole stock of solvent may not be weakened, this first portion, after traversing the ore, is discarded. The lixiviation of a vatful of washed ore is usually begun by running hyposulphite into the vat until it is about one-third full, the discharge orifice is then opened and the diluted solvent is run to waste, the feeding supply being kept on. As soon as the discharge, on being tested with calcium sulphide, shows traces of precipitate, it is run into a special receptacle. When the samples from the discharge yield tangible precipitate, the solving of silver chloride has begun, and the liquid is run into the precipitating-vats proper. The liquid in the special receptacle, after receiving an addition of calcium sulphide for the recovery of the small amount of silver it contains, is run to waste. At the end of the lixiviation, the ore-mass is saturated with hyposulphite solution, and the reverse of the above procedure is carried out; water is admitted to the spent ore, takes up the hyposulphite, and is run into the stock of solution. The plan described of running to waste a few cubic feet of the hyposulphite solution each time a fresh batch of ore is treated, besides serving to prevent the dilution of the whole stock of solution, serves also to keep within bounds the concentration of foreign salts within it. The presence, even in coarsely crushed ore, of a considerable proportion of slime, renders the extraction of the intermixed common salt and sodium sulphate, by leaching with cold water, slow and tedius; these salts are not entirely removed in this first leaching, and traces of them

are therefore taken up by the hyposulphite solution used in the second leaching. Further, sodium chloride or calcium chloride, as the case may be, must of necessity be formed in the stock-solution as a consequence of the reaction which attends the solving of the silver chloride in it, or of the solving of basic chlorides of other metals; this reaction may, in the case of the sodium-salt, be thus expressed, $2NaS_2O_3 + 2AgCl = Ag_2S_2O_3 + 2NaCl$. The entry of foreign salts into the stock-solution would gradually render it useless as a solvent.

In the Russell process the ores are first treated with a solution of sodium hyposulphite, and then with a solution of a double hyposulphite of sodium and copper. The latter solution is made by adding sulphate of copper to the former. It exercises an energetic solving action on metallic silver and on various salts of silver which are not acted on, or only slightly acted on, by an ordinary hyposulphite solution. Its action on silver sulphide, whether existing alone or associated with antimonial and arsenical sulphides, is particularly important. When the chloridizing roasting of an ore is imperfectly carried out, these compounds, in an undecomposed or only partially decomposed state, are of frequent occurrence. Under the treatment of the ordinary lixiviation process they resist the action of the solvent employed, and are wasted in the tailings; whereas, under the treatment of the Russell process, they are to a large extent decomposed and brought into solution. With ores which have been submitted to a thorough chloridizing roasting, the use of this process offers no advantages over that of the ordinary process. In fact, the ordinary hyposulphite solution is a better solvent of silver chloride than is the double hyposulphite solution. Also, when cupriferous ores are treated, the advantage of the Russell process over the Patera process disappears. The cupric oxide and cupreous chloride, formed during the roasting of the ore, are not removed by the leaching with water, but are dissolved in the calcium hyposulphite solution of the second leaching, and confer on it the properties of double hyposulphite solution. If, therefore, copper is present in the ores treated, the solvent employed in the Patera process is, to all intents and purposes, a solution of cupreous-calcium-hyposulphite. The fact that the Patera process is able to treat all copper-bearing argentiferous ores with most excellent results was known from the earliest days of its use; but the reason why the presence of salts of copper influenced the extraction of the silver was not known until the results of Mr. Russell's exhaustive experiments on the solubility of combinations of silver, in solutions

of double salts of sodium and copper hyposulphite, were published[1] by Mr. Stetefeldt. The fact that with many types of ore the successful working of the Russell process is less dependent on a perfect chloridizing roasting than is the case with the Patera process, gives the former a great economic advantage over the latter. At the Yedras mines this advantage was very great—so great as to cause the abandonment of the use of the older process and the adoption of the newer one. The saving effected by the change amounted to $6 or $7 per ton, less the charge for royalty. A detailed account of the comparative working of the two processes has been given[2] by Mr. Rockwell. The nomad character of the labour at these mines rendered thorough chloridizing roasting impracticable, and the ore dealt with did not contain a vestige of copper. On the other hand, at some of the pioneer lixiviation works in Sonora, where these two important conditions were reversed—the chloridizing being carried out with trained roasters, and the ores treated being cupriferous—the experiments made with the Russell process showed the same results as those obtained from the Patera process. By the introduction of the Russell process the sphere of usefulness of lixiviation methods of treating silver ores is considerably enlarged.

The use of the extra solution is the distinguishing feature of the Russell process. But, to the operator by the Patera process, the fact that the calcium hyposulphite and calcium sulphide used in that process as solvent and precipitant are, in the Russell process, replaced by sodium hyposulphite and sodium sulphide, is of more immediate interest. Mr. Stetefeldt, in his essays on the Russell process, points out that the method used therein for precipitating as carbonate the lead contained in the silver lixivium prohibits the use of calcium hyposulphite as solvent, but that process loses nothing by this inhibition; that, on the contrary, the use of these salts of calcium is, in every way, less advantageous than that of the corresponding salts of sodium. Sodium hyposulphite as solvent, and, consequently, sodium sulphide as precipitant, were used originally with the Patera process; they are now used with the Patera process at some of the mines of the Barrier Range, New South Wales. But, at the time of the first working of the process in Sonora, the means of transport to manufacturing centres were very costly, and it was the object of endeavour of those engaged in

---

[1] "Transactions of the American Institute of Mining Engineers," vol. xiii. p. 47.

[2] "The Engineering and Mining Journal of New York," vol. xlv. p. 86.

mining and milling to carry on their operations as far as possible with such supplies as could be obtained in the country itself. As long as sodium sulphide was used as precipitant, the caustic soda needed for its manufacture had to be brought in from abroad, whereas the caustic lime needed in making calcium sulphide was obtainable, in the majority of cases, in the vicinity of the works. When it is considered that beyond the high cost of transport opportunities of effecting it were both infrequent and unreliable, and, further, that caustic soda is an inconvenient substance to convey on pack-animals, it will be seen that strong inducements existed for the preferential use of the calcium salt. The custom of using calcium hyposulphite and calcium sulphide, therefore, became established, and, coincidentally, came in the belief that, of the hyposulphites of the alkalies or of the alkaline earths, those of lime were best suited for use in this branch of metallurgy. It is, however, true that a solution of calcium hyposulphite is not superior to a solution of sodium hyposulphite as a solvent, whilst it is inferior to the latter in stability. And so with the corresponding precipitating solutions, calcium sulphide possesses no point of superiority over sodium sulphide, and, in at least two important respects, consumption of material when in course of manufacture, and stability when in use, is inferior to it.

Treatment of the Sulphides.—The precipitate which is obtained by the lixiviation process is, after being thoroughly dried, either melted and run into bars of impure bullion, or subjected to a mixed scorification and cupellation process. In some few cases, however, it is simply packed in bags and boxes, and shipped for sale to foreign refineries.

The drying is in nearly all cases effected in reverberatory furnaces. These are made quite narrow, a width of about 7 feet being commonly adopted. The length given to them is dependent on the amount of material to be dealt with; frequently it is about 15 feet. Since the object aimed at is to expose the precipitate, not to contact with flame, but to the action of a current of hot air, the fireplace is made very small. A chamber is interposed between the drying-hearth of the furnace and the fire-bridge, and the products of combustion of the wood burnt on the grate are mixed in this chamber with heated air drawn through channels in the brickwork. The sole of the hearth, which receives the wet precipitate, is placed over a vault which forms part of the dust-chambers; it is dried and slightly heated by the current passing through this vault. In view of the richness in silver of the precipitate, the use of muffle furnaces for this drying operation

has been suggested; but the furnace described above is cheaper to build and to keep in repair, and does its work satisfactorily. It might, however, be an improvement to cause the products of combustion to pass under the drying-hearth before entering it. When the precipitate is thoroughly dry, the temperature is sufficiently raised to ignite the free sulphur which is always present. As soon as this point is reached, all the fuel is raked out of the fireplace, and the combustion proceeds unaided. The mass is turned over once or twice, care being taken to almost arrest the draught of the furnace during this operation. The custom at one time prevailed of not only burning off the free sulphur, but of driving off part of the combined sulphur by calcining the product. This practice has very largely, and very properly, been abandoned; the substance is far too rich in silver to render such treatment judicious. The oxidation is far better effected in the cupellation furnace, where the liberated silver is at once seized upon and protected by metallic lead. On the other hand, it may be noted that precipitate is frequently dried by being pressed in filter presses and exposed to a current of air heated by contact with pipes through which steam is passed. If precipitate dried in this way is to be treated by cupellation, it seems desirable to first burn off the uncombined sulphur.

The process of refining the precipitate was, at Promontorios, carried out in cupellation furnaces of the German pattern, the hood being movable and the hearth fixed. The latter was circular in plan and 6½ feet in diameter. Wood was employed as fuel, and the marl used for the bottom was obtained by crushing a mixture of broken limestone and clay through a sieve with sixteen holes to the lineal inch. After the bath of lead, which weighed about 5 tons, was freed from the first impure litharge, the blast was kept on until the surface was again completely covered with litharge. The blast was then cut off and the draught greatly reduced, and between 150 lbs. and 200 lbs. of precipitate introduced with a ladle. Clean litharge, to the extent of three times the weight of precipitate taken, was then spread over the latter. As soon as the added material reached the pasty condition, the draught was restored, the blast applied, and the fire slightly urged. When the scum, which resulted from the fusion of a charge, was nearly liquid it was skimmed off, litharge was again allowed to form over the bath of lead, and a fresh quantity of precipitate was charged as before. In order that the scorification method of treating silver precipitate may work smoothly, and with a minimum of loss, it is essential to carry it out in furnaces of ample dimensions. When

this requirement is observed, the mixed sulphides may be brought in contact with many times their weight of litharge. The layer exposed to the oxidizing action of the blast is thin and penetrable, the decomposition of the sulphides is therefore rapid and complete. Part of the copper contained in the precipitate is absorbed by the bath of lead, but in large furnaces is so diluted as to have comparatively little ill effect. When the yield of copper in the precipitate is large, the lead bath is maintained in good condition by, from time to time, interrupting the charging of precipitate, and by feeding soft lead into the bath until its surface becomes bright. With the view of keeping at the lowest point the amount of copper which is taken up by the lead, the refining operation is conducted at the lowest temperature practicable. The precipitate, when mixed with large amounts of litharge, is fairly fusible, but it is not necessary to employ such a temperature as to completely liquefy the slag or scum which results from its fusion, or partial fusion. The commercial product obtained from the above described scorification is rich argentiferous lead containing some copper, and its subsequent treatment is simply one of cupellation. This is effected in a smaller furnace of the same pattern, or in the English test-furnace. The litharge and the scum which are produced in the refining-process are reduced in blast furnaces. At Promontorios and at Minas Nuevas the lixiviation process and the lead-smelting process were both in use, and the lead products from the refinery were added to the smelting mixture; their contained copper was collected in the mattes. The dried precipitate submitted to the refining operation at the Promontorios works contained about 20 per cent. each of silver, copper, and lead. These proportions, of course, varied over wide limits. The yield of silver lay between the extremes of 14 per cent. and 35 per cent., and the yield of copper between 15 per cent. and 27 per cent. It may be noted that the average fineness in silver of the precipitate, obtained by the lixiviation process from ores which are comparatively free from lead and copper, is from 45 per cent. to 55 per cent.

The lixiviation process is not applicable to the treatment of gold ores. Of the small yield of this metal contained in the silver ores submitted to the action of the process, from 50 per cent. to 70 per cent. is obtained.

One of the useful applications of the Patera process is the treatment of the argentiferous zinc blende, which is obtained by the hand-sorting and mechanical sorting of mixed ores of blende and galena. The important point in connection with the treatment of these sorted products is the degree to which it is necessary to

carry the separation of the galena. With the ores treated at the Promontorios works, the separation of the galena from the blende by the hand-pickings, the sizings and the jiggings which were resorted to, was not perfect; blende was retained with the galena separated for smelting, and galena accompanied the blende set aside for treatment by lixiviation; the slimes, in particular, contained a considerable proportion of galena. It was found that, what may be called the permissible content of lead, in the case of these ores, for economical treatment by the Patera process, was passed when 8 per cent. of that metal was present in the roasted pulp: with this amount of lead the consumption of precipitating reagent was equivalent to 11 lbs. of sulphur for each ton of ore treated. The average consumption of sulphur at these works was 6·7 lbs. per ton of ore treated, so that the average content of lead in the roasted pulp was well below the point named above. A comparatively small proportion of the ores extracted from the mines consisted of a fine-grained variety of mixed ores of blende and galena; the two sulphides could not be separated by jigging, and these ores, in admixture with large amounts of ores poor in zinc, were therefore smelted. The Patera process is not competent to deal with those varieties of zinc-lead-sulphide ores in which these sulphides cannot be separated—or, rather, partially separated—by mechanical dressing. An exception to this statement occurs when the yield of lead in this practically unsortable variety is low; the process is competent to deal with these mixed ores when this condition is fulfilled. Its use for this purpose has largely increased of late; the Author found it in use, in the treatment of argentiferous blende ores carrying some galena, in the Peruvian Andes some three years ago, and was informed that it had also been introduced into Chili for a similar purpose; its somewhat extended employment in New South Wales has been, for the most part, in connection with the treatment of this same class of ore. When its use is practised with the segregated product from the dressing of these mixed ores, the mode of preparing the slimes from the dressing works, for entry into the chloridizing furnaces, calls for a little attention. At Promontorios, the slimes produced during the crushing of the mixed blende and galena were not dressed; long-continued experiments showed that a series of washings on endless belts and inclined planes, failed to remove the silver sulphide contained in them; they were merely roughly sorted by being passed over strips, the headings obtained were added to the smelting ores, and the whole of the residue was settled in reservoirs and added to the lixiviation ores. These

slimes formed in drying hard lumps, which were impermeable alike to the chloridizing action of the roasting process, and to the attack of solutions; they were prepared for entry into the chloridizing furnaces in the following manner. The contents of the slime-pits were run on an inclined paved surface and allowed to drain and partially dry, and were then fed into a Pacific dryer. This apparatus differs but slightly from the rotating-cylinder roasting-furnaces of the continuous action type; its cylinder is made of cast-iron and is not protected by a brick lining. The dimensions of the cylinder are: length 18 feet, diameter at the feed end 3 feet and at the discharge end 4 feet; it is set with its axis horizontal and the inclination needed for the advance of the ore is furnished by its taper; for such purposes as the drying of slimes the dimensions above given might advantageously be increased. The dried product passed into a Bruckner ball pulverizer—a cylinder in which the material treated is rotated together with a number of iron balls, and to part of the periphery of which a sieve is attached.

Both these appliances worked economically; the dryer is, for convenience of carriage, made in short rings, but, when the mode of transport is by pack-mules, it is further "sectionalized"; at points where freight is extremely dear a convenient substitute for this apparatus is a long reverberatory furnace, the hearth of which has a very steep inclination from the flue end to the point of discharge.

Cost of Working.

The cost of ore-reduction by the lixiviation process is influenced by and, in great measure, dependent upon the chemical and physical constitution of the ore, the local conditions, such as the prevailing rate of wages and the price of supplies, and the facilities for handling the ores and products offered by the plant. The most important item of cost is that of the chloridizing roasting of the ore, and this fluctuates between very wide limits. The influence exercised by the character of the ore is most marked on this branch of the expenditure, since, when ores of a favourable type are roasted, the daily capacity of a chloridizing furnace may be nearly twice that which can be reached when ores of the opposite type are roasted. The influence exercised on the cost of roasting by variations in the local conditions is less marked, still it is considerable. The most important of these variations is that in the quality of the labour obtainable in the different localities; in some parts the furnace

work is carried on with trained and reliable roasters, and in others with untrained and unreliable labourers; the rate of wages paid for this work does not vary much, commonly it is between 75 cents and $1 per day. The only articles of supply, the price of which affects to any large extent the total cost of roasting, are firewood and common salt. The price of the former may vary, at different points, between $3 and $8 (Mexican silver dollars) per cord of 128 cubic feet, and that of the latter between $15 and $40 per ton of 2,000 lbs.; the principal factor which governs the price of each is the cost of freight from the sources of supply to the reduction works; the consumption of wood is between 0·15 cord and 0·20 cord per ton of ore roasted. In the leaching department, the main item of cost is that of sulphur, the consumption of which varies, according to the nature of the ores treated, between 4 lbs. and 9 lbs. per ton of ore; its price is between 5 cents and 8 cents per lb. The amount of quicklime used is between one-and-a-half and two-and-a-half times that of the sulphur, and its price is generally about 1 cent per lb.; sodium-hyposulphite is rarely used. Under the varying circumstances enumerated, the total cost of treating ores ranges between $7 and $13 per ton. As is to be expected, the aggregate of circumstances which moulds the cost of the work is rarely entirely favourable or entirely unfavourable, one set of conditions roughly balances another set, so that the average cost of treatment, at works treating between 40 tons and 50 tons per day, is about $8 to $9 per ton in the coast districts, and $11 to $12 per ton in the mountain districts. The process is a favourite one with owners of small mines; in the reduction works with which such mines are equipped, say with a capacity of 20 tons per day, the ratio of cost of management to that of total cost is a high one; such works are, however, usually directed by the owners. The most important economy is that to be expected from the introduction of improved methods for roasting the ore; the adoption of mechanical roasting furnaces, or the use of reverberatory furnaces of large dimensions, would undoubtedly effect a considerable saving in the cost of working.

The Paper is accompanied by three drawings, from which Plate 2 has been prepared.

(*Paper No. 2912.*)

"Mining and Treatment of Copper Ore at Tharsis, Spain."[1]

By Charles Frederick Courtney, M. Inst. C.E.

In the development of the Tharsis mines four periods of well-defined activity can be traced, the Prehistoric, the Phœnician, the Roman and the Modern.

During the first, the emergence from the stone period is indicated by the quantities of stone implements, made from the hard porphyry of the surrounding country, which have been from time to time found in the mines and caves of the district.

The second period occurred during the Phœnician occupation of Spain, which, according to Josephus, was 240 years before the building of Solomon's Temple, or about 1,200 years B.C. Gades (Cadiz) was then one of the most important ports, and only six hours' sail from Huelva; it may be assumed that the Phœnicians were at or near the Andalucian group of mines about this time. The period of their domination may be also ascertained, for the weakening effect of the inroads made by the Assyrian monarchs was so disastrous to their trade that their great power in their colonies was broken. The Carthaginians, taking advantage of their difficulties, are found to be making inroads into Spain, and depriving the Phœnicians of their authority, about 650 B.C. There is no distinct evidence of the mines having been worked about this time, although the fact of several heaps of a rough and spongy class of scoriæ being in close proximity to the lodes, and always near an abundant spring of water, has strengthened the belief that these heaps are the refuse of Phœnician smelting. The complete absence of Carthaginian mining enterprise in the province indicates that the Romans, in becoming masters of Spain, must have rediscovered the mines; and that between the Phœnician and the Roman domination, 200 years B.C., or a period of 400 years, no mining work was carried on in this district.

During the third, or Roman period, the population drawn together for the purpose of trade and mining numbered millions, and remains can now be seen of an industry that was undoubtedly

[1] The discussion upon this communication was taken in conjunction with the preceding and the following Papers.

colossal; roads, amphitheatres and aqueducts abound, as well as numberless articles of jewellery, copper pots and pans, coins, mining-lamps, and water-wheels. It is difficult to imagine how so great an amount of ore as that represented by the slag-heaps which cover the ground was extracted through the tortuous galleries at present existing. Many miles of railway and road have been ballasted with this slag, and still the volume is not perceptibly reduced. These slags are as fresh and clean in outline now as they were when run from the furnace 2,000 years ago. It is indeed strange that so vast an industry as was here established, of 500 years' duration, could so completely have ceased. For 1,000 years there was again an absence of work in the district, partially accounted for by the Moorish domination of 410 A.D.

The renewal of activity by the Spaniards marks the opening of the fourth or modern period, and may be traced to the desire for riches induced by the discovery of America. In the year 1866 the present company was formed with a capital of £300,000 to take over the mines and property from a French company; and, as the working of the lodes developed, it was found necessary from time to time to increase the capital, which now stands at £1,250,000. Since the commencement of operations by the present company 508 per cent. has been paid in dividends, and £1,884,885 written off the property, plant, &c.

The composition of Roman slag is compared with that of modern slag in the following Table. Phœnician slag differs from the Roman and modern slags in containing between 2 per cent. and 3 per cent. of copper.

—	Roman Slag.	Modern Slag.
	Per Cent.	Per Cent.
FeO	50·81	46·59
Fe	0·46	2·40
Fe_2O_3	4·48	Trace
Al_2O_3	6·85	6·80
CaO	2·23	0·90
Cu	0·12	0·47
Zn	None	0·58
PbO	1·00	None
S	None	1·60
KNaO	0·28	1·06
MgO	0·31	0·38
Silica	32·80	38·15
Moisture	0·16	None
Combined moisture	0·89	None
	100·39	98·93

Geology of the District.

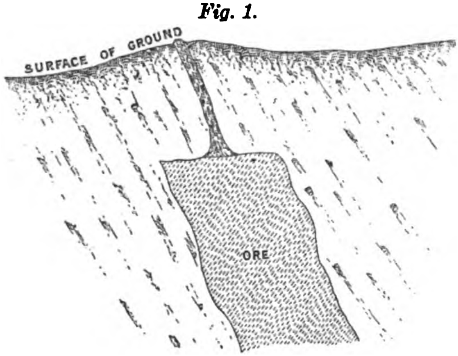
The property of the Tharsis Company consists of the Calañas lode, from which the export ore is at present drawn, the six lodes in Tharsis, the main establishment, and the newly acquired Lagunazo mine about 5 miles distant. The Calañas mine, about 18 miles distant, is connected with the main establishment by railway, and a line, 29 miles in length, connects Tharsis with the port at Huelva.

To the south of the Sierra Morena, and forming part of that range, there is, extending from near Seville and running into Portugal, a zone of clay slate between 110 miles and 120 miles in length, which encloses the enormous deposits of cupreous iron pyrites at Rio Tinto, Tharsis, and San Domingos. The course is in a north-westerly direction; and parallel to the deposits of ore, dykes of quartz-porphyry occur, there being in some parts a difficulty to distinguish the slate from the porphyry. These dykes and intrusions are, however, generally prominent, and the enclosing rock is believed to be of either Silurian or Devonian age. The lodes are about 800 feet above the level of the sea, and the colouring of the surrounding country and their immense iron capping form prominent features of the district. The masses of ore are of a more or less lenticular form, parallel to the enclosing slate, and of great length and width, being as much as 2,600 feet long, 65 feet to 500 feet wide, and in most cases of great depth. The upper portion, having absorbed the copper liberated by the oxidation of the outcrop, contains as much as 3 per cent. or 4 per cent. of copper, whilst at a depth of 300 feet to 400 feet, unoxidized specks of yellow ore are found, giving the mass only ½ per cent. of copper. In this form, the ore, both from poverty in copper and compactness of structure, becomes useless for either export or local treatment. Owing to the rapid decomposition of the pyrites, the existing ironstone outcrop or capping marks very perfectly the underlying mass; and the enclosing slate, by the action of the acid salts, has become soft and of a yellow, red, and black colour. When the hydrated oxide of iron of the capping is associated with silver and other metals, these may be considered as an inset to the occurrence of cupriferous pyrites at greater depth. *Fig. 1*, p. 129, shows the form assumed, and the connection between the gossan and the lode. One of the lodes of the Tharsis group, however, merits special mention, as it is, at least in this district, unique, consisting of slate that has been impregnated by cupreous liquors. Such deposits are restricted to sites that have received the natural liquors produced by the oxidation of pyritic lodes at their outcrop,

and have originated in the action of these cupreous liquors upon slate containing disseminated sulphide of iron and zinc. The most characteristic indications are depositions of ferric oxide, either in blocks forming a conglomerate, or as films upon slate or other rocks.

The whole mass, of 2,300 feet length, with an average width of 197 feet, and depth of 98 feet, contains very little copper, its amount seldom exceeding 1½ per cent., and corresponds exactly to the outer case of the pyritic lodes, where the ore, being in contact with the slate, has caused the latter by impregnations to become soft. Such deposits are very easily and economically worked, and permit of profitable extraction with a copper contents of a little

Fig. 1.



over ½ per cent. The composition of the ores is as shown in the following Table.

—	Cupriferous Iron Pyrites.		Cupriferous Schist.
	Export Ores.	Local Treatment Ores.	Local Treatment Ores.
	Per Cent.	Per Cent.	Per Cent.
Iron	43·10	42·80	0·10
Sulphur	49·50	48·30	0·15
Copper	2·50–3·00	1·50–2·00	1·00–1·25
Lead	0·30	1·30	..
Zinc	0·80	1·80	0·05
Arsenic	0·40	0·70	..
Water	0·50	0·80	3·15
Silica	0·60	0·70	93·60
Oxygen and various metals	1·20	1·10	..
	99·40	99·50	98·30
Specific gravity	4·50	4·50	2·25

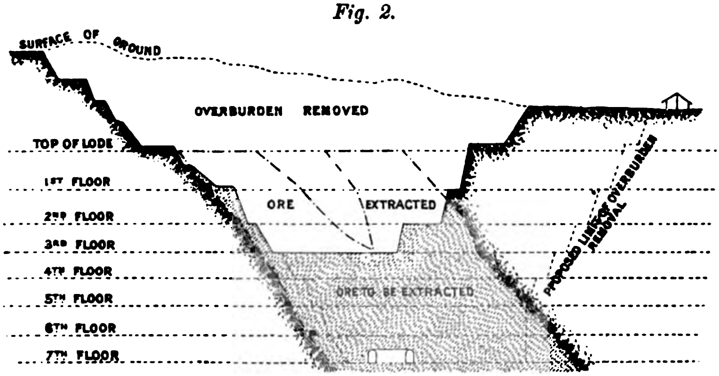
Methods of Mining.

Three methods of mining have been employed at Tharsis for the extraction of the ore. The pillar-and-stall system has been largely adopted, and by it somewhat over one-third of the entire mass can be extracted without the necessity of support or danger in working, the ore being very compact. Each floor has a height of 33 feet, and parallel galleries are driven through the entire length of the lode, 16 feet by 16 feet and 33 feet from centre to centre. A partition is left 16 feet thick, which is afterwards broken through in stalls of 16 feet width and 33 feet centres; the stall of one partition corresponding with, or facing, a pillar in the opposite partition. Great care has to be taken in the surveying of the various levels, as the safety of the lode depends upon the pillars falling vertically over or under each other on their superior or inferior floors: large faces of ore are exposed, affording freedom for the men in winning, and enabling the extraction to be continued with regularity. Each floor has a fall of not less than 1 in 150 towards the extraction shafts, which is found sufficient for both drainage and easy traction. The ore when broken down by the miners is loaded by a separate gang into small wagons, of 1 ton capacity, running in a 2-foot 6-inch gauge line, and made up into trains of three or four wagons for mule traction to the shafts. Each miner wins 2 tons per day, and a filler averages 20 tons per day of eight and a half hours, the consumption of dynamite No. 1 being about 0·175 lb. per ton. The miners and fillers are generally on contract and earn 3*s.* and 2*s.* 6*d.* per day respectively. By this system the ventilation is excellent, there are therefore no delays from dynamite fumes after blasting. The dryness of the ground has always facilitated underground working, as not more than 30 gallons per minute of liquor per day is given by these large lodes.

The large amount of ore that was left in the lodes after working on the foregoing system led to the contemplation of other methods; and finally, after much thought and consideration, a bolder scheme was inaugurated—that of removing the overlying rock. The open casting of these lodes has been at work for many years, and some of the largest excavations in the world may now be seen in this province. The dip of the ore, not being more than 60°, assisted the open-cut system of working; whilst the more economical mining of the ores afterwards has permitted a very large amount of overlying rock to be removed profitably per ton of ore rendered available. Six hundred and fifty-four thousand cubic

yards have been removed from the surface of one lode within a year. The method employed, *Fig. 2*, is that of dividing the over-burden into floors, 33 feet in height, leaving a slope of 60° and a bank of 13 feet width; this gives an average batter of about 45°, allowance being made for the varying conditions of the hanging- or foot-walls. The hanging-wall permits of a batter of 3½ in 10 being given as against 5½ in 10 for the foot-wall. There is, however, no set rule, the slopes in all cases being governed by the strength or compactness of the enclosing rock; but this condition and the copper contents are conjointly the factors which fix the cube that can be allowed per ton of ore made available. From the large open cuttings, many banks being over 1,600 feet in length, a miner will blast and break down 250 cubic feet per day of eight

Fig. 2.



SECTION ACROSS A MAIN LODE SHOWING ORE AND OVER-BURDEN REMOVED.

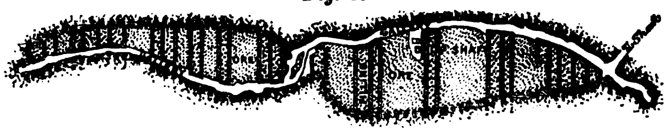
Scale, 240 feet to 1 inch.

and a half hours at a wage of 2*s.* 6*d.*, whilst a filler at 2*s.* 2½*d.* per day, assisted by a carrier to wagons at 1*s.* 3¾*d.*, will give 424 cubic feet during the same time. As in this case the work is generally by task rather than by contract, a closer supervision is required over the consumption of dynamite, the average amount used being 0·168 lb. No. 3 per cubic yard. An excavation that advances with the line of stratification will require one-half more dynamite than if advancing at right angles to it; it is therefore always advisable in open casting a lode of considerable length and ample width to drive a trench in advance, giving in this way a minimum of work with the stratification and a maximum at right angles to it. Whether the dip be great or slight, the work should always, where practicable, be commenced on the

hanging side, working towards the foot-wall, there being a considerable difference in the consumption of dynamite in favour of working with, as working against, the dip. After the removal of the over-burden the extraction of the mineral becomes much easier and consequently less costly. Each man will blast down 8 tons at a wage of about 2*s.* 8*d.* per day, as against 2 tons per man in close workings at a wage of 3*s.* per day, loading in both cases being about the same, whilst the consumption of dynamite No. 1 is about 0·099 lb. per ton in the open cutting, as against 0·175 lb. in underground workings. The advantage is, therefore, that the whole of the ore uncovered by the removal of its over-burden is rendered available for extraction, the lower cost of extraction more than paying for the removal of the superincumbent rock.

The third method of mining is more or less an adaptation of the long-wall system, and permits of the whole of the ore being

Fig. 3.

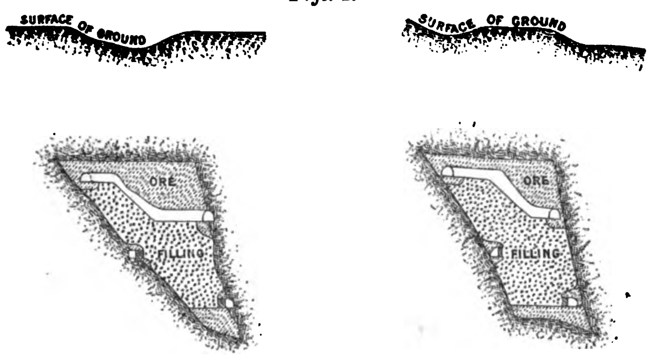


PLAN SHOWING METHOD OF EXTRACTION BY BUILDING AND FILLING.
Scale, 340 feet to 1 inch.

removed by underground working. The lode is divided longitudinally at equal distances by diaphragms or walls, starting at the bottom level and working upwards, between each wall a space being left equal to their thickness, afterwards to be filled with loose rock or earth as the overhead extraction continues. This system, though expensive in working, has been adopted for the extraction of the ore from one of the lodes the form of which lent itself readily to the operation. The usual underground working would have given, as before stated, about one-third of the whole mass, the richness of the ore warranting a more expensive system of working though not the removal of its over-burden. This mass of ore, known as the Poca Pringue lode, contains about 3·75 per cent. of copper, its length being 679 feet, and having an average width of 52 feet, being evidently a spur from the adjoining lode, although separated therefrom, as it runs out at a depth of 112 feet. The lode is divided into floors 33 feet in height, and a gallery at each floor runs along one side of the mass, assisting ventilation and enabling the extraction to be carried on easily. Operations

begin at the lowest level or floor, the entire length being subdivided into spaces of 4 feet alternating with those of 8 feet in width, the 4-foot spaces being reserved for building in dry stone and the 8-foot spaces for filling. Galleries are driven across the lode at the bottom of 16-foot width, and the excavation continues upwards by overhead working. As the ore is removed the dry-stone walls are built along each side of the excavation, the centre portion being filled with waste. When the ore appertaining to this section is extracted there is left in its place a diaphragm from the bottom to the top of the mass composed of two dry-stone walls enclosing rough filling. Whilst this section is being worked, other

Figs. 4.



SECTION SHOWING METHOD OF EXTRACTION BY BUILDING AND FILLING.
Scale, 240 feet to 1 inch.

portions of the lode are being attacked in the same manner, the upper exterior galleries being used for the supply of stone, &c., for building and filling, whilst the lower galleries serve for the loading of the extracted ore. The stone for building and the waste for filling are obtained from the open cutting of the adjoining lode, being selected during removal and deposited near an automatic drop-shaft by which it is passed when required to the workings below. No difficulties are experienced from any movement or creep of the hanging-wall. The whole operation of mining, dry-stone packing and filling, with the present low market prices for copper, sulphur, &c., requires about 1·50 per cent. to 1·60 per cent. of copper per ton of ore obtained to cover the costs of working.

Machinery.

The shafts vary in size considerably, some being large enough for a double cage, and others for a single cage only; the output, however, for each shaft may be considered as between 900 tons and 1,000 tons per day, drawn from an average depth of 295 feet. The shafts are fitted with ordinary cages, safety-hooks and automatic gong indicator in the engine-room for the starting and delivery of the wagons. At the shaft mouths there are extensive platforms, along one side of which a series of tumblers is arranged by which the wagons are turned completely over by their own weight, righting themselves again when empty. To the tumblers are connected shoots at an angle of 36° in the form of riddles of ¾-inch spaces, to allow the mineral for export to be cleansed of its smalls, which amount to about 17 per cent. of the whole weight. The smalls are sent to the local treatment ground for the extraction of their copper, and the reduction of the liquors before precipitation; other shoots are fitted with the Blake type of crushers or stone-breakers by which the ore is reduced to the required size for local treatment. These crushers have jaws 24 inches wide, and are capable of crushing 40 tons per hour at a cost of 2¼*d.* per ton. The channelled and ribbed jaws of chilled iron are reversible and withstand the crushing of 1,700 tons each; they have therefore to be constantly replaced, and provision is made for their easy removal. An automatic balance-feeder is also attached to the end of the riddle where the ore drops into the crusher, to prevent the whole wagon-load rushing into the jaws and causing them to jam. By these arrangements very little labour is required to keep the crushers constantly fed; the ore after being crushed drops through a funnel into the wagons waiting for its reception beneath, and is ready for weighing before being drawn off in trains of twenty wagons to the local treatment ground.

Each shaft is fitted with a 12-inch bucket-pump for dealing with the drainage water, although the ground, as before stated, does not yield much water; the extent of the open cutting accumulates large quantities, which run in upon the lower floors suddenly, and sometimes requires heavy pumping for a few hours, especially during wet seasons or thunderstorms. As these liquors are very acid, and give great trouble by rapidly eating into the metal of the pumps, an alloy containing one part of antimony, two of lead, three of tin, and fifteen of copper for cylinder buckets, valves, etc., though difficult to cast, has been found to give the most excellent results, whilst for bolts, nuts, etc., one part of lead, two of tin, and

seventeen of copper, is preferable to withstand blows or strains, being more ductile.

The workshops are well fitted with modern machinery, and all the smiths, mechanics, fitters, boiler-makers and carpenters are Spaniards. All locomotive and wagon repairs are carried out at the mines.

Treatment of the Ore.

The old and simple method of extracting the copper was by calcination, the sulphide of copper during the process being turned to cupric sulphate, and the ore to a spongy condition by the consumption of its sulphur; the copper was then very readily washed out with fresh water. A large area of ground was occupied by the ore both in active calcination and that which had been calcined, being first conveyed to the site, either crushed by the crushers at the pit's mouth to the requisite size, or hand-broken when tipped on the ground. Long triangular heaps were built, having a series of rough dry-stone flues and chimneys, with brushwood in mounds placed at intervals of 13 feet; these heaps were built parallel to one another, and mostly 98 feet long by 16 feet wide and 8 feet high, containing about 330 tons. The exterior was carefully covered with the finely riddled smalls or burnt ore that had been previously washed; this enabled the combustion to be controlled, and great care and experience were necessary to ensure a perfect calcination. These heaps were generally burning five, six to eight months, or, as was found by experience, a month for each metre-width of the heap; about 12 per cent. of weight was lost by calcination, and 84 per cent. of the copper made soluble; this permitted the ore to be washed down to 0·20 per cent. of copper, with five consecutive washings. When cold, the heaps were broken open, loaded into wagons, and the material conveyed to the dissolution tanks, into which it was tipped. Here it was saturated with water, the resultant liquor being drawn off when clear; by this process six or seven waters were generally found sufficient to extract the copper, each successive saturation being given greater time; the resultant liquors were passed to a settling-dam, and drawn off as required by the precipitating plant. When the copper in the ore was reduced to about 0·20 per cent. the tanks were cleaned and the washed ore deposited on a site conveniently near, where the residual copper was extracted by further washings; by this process 2½ tons to 3 tons of iron were consumed to produce 1 ton of fine copper, whilst the quality of

the precipitate was very poor, often not reaching 60 per cent. of copper.

It was found, however, that by passing the liquors from the lixiviation of the calcined ore over the crude smalls as a filter, a marked change took place, the ferric sulphate being very readily turned to ferrous sulphate, as the copper was taken up from the smalls. This gave an almost ideal liquor for precipitation purposes, and by the development of this process under constant care the consumption of iron in the precipitation of the copper from these liquors was reduced to 1·25 per unit of copper produced, and the quality of the precipitate raised to 80 per cent. Here, then, was a great advance upon the old system; the cost of handling the ore was reduced at once by one-half, and later, this was brought down to a minimum of expense by the burnt heaps being washed *in situ.* The new heaps of crude ore being built upon those that were already washed, there was ultimately only the cost of traction from the pit's mouth to the calcination ground, the making into heaps, calcination and lixiviation, by either washing the burnt ore in dissolution tanks or *in situ;* 35·32 cubic feet of water was used per ton of ore.

The nuisance caused by the calcination of upwards of 200,000 tons of cupriferous pyrites per annum can be readily imagined. Vast clouds of sulphurous-acid gas extended for miles over the country, withering up everything that they touched in their flight; many attempts were therefore made to abolish or at least modify this nuisance, but without result. Many chemical treatments were tried, and were, apart from their partial success, prohibitive in consequence of their expense; the necessary economical treatment of such low-grade ores was a drawback against any complicated treatment. It was, however, ultimately found that an induced natural oxidation of the ores that were specially crushed and tipped in large deposits would, though taking slightly longer to obtain the copper than by direct calcination, give an equally good result, more economically, and at once abolish the noxious fumes. This process has now been working four years, and consists in first crushing the ores to a fineness that 45 per cent. would pass a 1-inch sieve with only 10 per cent. larger than 2 inches; tipping in heaps as large in area as possible, 33 feet in depth, the whole ground occupied by the deposit being laid out in a network of dry-stone drains for ventilation and drainage. Occasional small shafts were built up in the heap for purposes of testing the temperature, a record being carefully kept of these readings for reference, as the success of the operation

consists in maintaining a regular heat through the deposit. Ores containing so much sulphur oxidize very readily, and the heat generated in the deposit is also influenced by the percentage of copper contained in the ore. By a very careful system of intermittent washing with fresh water, oxidation is encouraged, and, three months after washing operations begin, considerable heat is noticeable in the heap; in six months, the full heat that can be permitted is attained, and from that time forward a check has to be kept on the general temperature. As the copper is washed out, there is a tendency for the heat to subside. As far as experience has indicated, the temperature should not be higher than 120° F., whilst below 70° the rapid extraction of copper is retarded. From ores containing between 1 per cent. to 1·50 per cent. of copper, 45 per cent. of the total can be washed out during the first year, 20 per cent. the second year, and 10 per cent. in the third year. This leaves a small residue, obtainable if desired by light washings. After three years' washings the original tonnage laid down for treatment is reduced by 23 per cent. in consequence of its loss in copper, sulphur, iron, etc. Ores richer in copper will yield a better result, the poorer class slightly worse in consequence of their origin in the lower floors where it is unoxidized and more compact in structure. The top of the heap has a gradient of not less than 1 in 300, which is formed in tipping, and the whole surface is divided into equal areas by shallow drains made with the finer ore, along which the water is conveyed to such parts as are under treatment. The water filters rapidly through the heap, taking up the sulphate of copper produced by oxidation; the whole of the water used in washing, less 19 per cent. absorbed and evaporated, is caught by a main drain which conveys it to a valley filled with what are locally called smalls, given by the screening of the export ore. There being over 750,000 tons in this valley, the area is large and forms a convenient filter for the reductions of the ferric sulphate in the liquors received from the upper heap. Besides the advantages gained in the suppression of the smoke, the ore, after it has been under treatment three years, becomes a valuable asset, its sulphur contents giving it a decided commercial value. The whole process requires considerable care and attention, and is kept under working control both night and day by a number of trained assistants. The liquors obtained by the treatment contain per gallon on an average 210·3 grains of copper, 1225·3 grains of iron as FeO, 171·0 grains as Fe_2O_3, 1296·9 grains of sulphuric acid, 11·22 grains of arsenic, etc.; whilst after passing the filter the amounts are

273·4 grains, 1421·6 grains, 36·5 grains, 1366·9 grains, and 11·22 grains respectively. This liquor is passed on direct to the precipitating plant.

The cupriferous schist extracted from what is known as the Esperanza lode is tipped in a valley below, and in close proximity to the lode. The output amounts to a little over 300,000 tons per annum, and, as a similar extraction has been made for several years, there is now an immense deposit in the lower valley. The material is tipped as it is received from the lode and undergoes no preparation such as the mineral before washing. The most rapid and efficient method of obtaining the copper is to first give a saturation with an acidulated liquor such as is pumped from the mine, or a spent liquor from the precipitating department; and, after two or three months' rest, the heap is in condition for leaching with fresh water. The schist washes freely and there is but little difficulty in reducing its copper contents to 0·10 per cent. The liquors given by the leaching are not strong in ferric sulphate, and therefore a contact of short duration with small crude ore is sufficient to bring them into excellent precipitating condition; these liquors, though seldom rising above 140 grains of copper per gallon, produce, when passed over iron, a very fine class of precipitate, free of arsenic and assaying 87 per cent. of copper.

The quantity of water requisite for the efficient washing of the crude mineral is 440 gallons per ton of ore for the first year, 220 gallons per ton the second year, and 110 gallons for the third year. If the tonnage of ore laid down for treatment each year be more or less constant, it follows that during the third year the largest consumption of water takes place, as not less than 250,000 tons of ore are annually placed under treatment, besides 300,000 tons of cupriferous schist; very large storage reservoirs are required to enable the work to be carried on without intermission during the dry season, which may be considered to fall between the months of June and October. Provision has therefore been made in Tharsis alone for the storage of upwards of 572,000,000 gallons of water brought to the reservoirs by many miles of catch drains. The burning of the cupreous ores for so many years has cleared the country for some distance of vegetation, the ground is therefore in a condition to give a considerable proportion of the rain that falls; many tests have been made and the average over thirteen months was found to be 54 per cent. of the total rainfall.

The evaporation is very great and is found to represent, in the case of the largest reservoir, 96,800,000 gallons per year. During the months of July and August very great heat is ex-

perienced, the thermometer occasionally rising to 110° F. in the shade, with 85° for several weeks as a minimum; the healthiest portion of the year, however, corresponds to these hot dry months, and the most unhealthy towards the end of September or the beginning of the first autumn rains.

A Table is given in the Appendix of the rainfall for the last fifteen years and the evaporation for the last seven years.

Sampling.

In treating such large quantities of poor ores and schists accurate sampling and analysis form an essential part of the operation. The tendency has always been to err on the higher rather than the lower side; and, under various methods of sampling, designed either with the object or not of counteracting the human error, the same constant tendency is noticeable. It may be safely assumed that no large heap of cupriferous ores has ever given more copper than was originally returned by sampling and analysis; in fact, the whole history of the working of these immense heaps has proved that their copper contents were less than was at first estimated. As the utmost care and vigilance is required, a system has been instituted which is equivalent to mechanical sampling; each wagon at the pit-mouth, as well as on the tipping ground, yields its quota, a method which ensures never less than two returns, and in many cases a third sample is independently taken. The undoubted possibility of error, coupled with the absorption of the ground, etc., makes it impossible to expect that the whole of the copper in the ore laid down for treatment is ultimately obtained.

Precipitation of the Copper.

The general disposition of the ground and its natural fall around the lodes has been taken advantage of in the arrangement for the supply of fresh water, etc.; the valleys running from the fresh-water reservoir being utilized in the upper portion for the tips of crude ore, below which there are the filter-beds and a series of collecting dams, and, finally, in continuation, the precipitating plant. The most approved method of precipitating the copper from its liquor is by passing it over pig-iron laid in a double layer in canals constructed especially for its reception. These canals, of creosoted timber, are 2 feet 9 inches wide with a depth of 9 inches laid in quadruple, triple or double series; if the fall of the ground

permits, about half the total length is laid with a fall of not less than 1 in 200, a quarter of the length following with 1 in 100, and the final quarter with 1 in 50. This arrangement permits of a gradually increasing agitation of the liquors as they advance and become poorer in copper, thereby improving and enriching the precipitate produced. One metre length of canal of the above dimension holds 573 lbs. of iron, and is capable of producing one ton of fine copper per annum. There is, therefore, considerable length of these canals employed at the mines, the total reaching 9,624 lineal yards, the pigs of iron used are 2 feet 6 inches long, weigh 33 lbs, and contain on an average 94 per cent. of iron. The liquors on entering the service contain per gallon on an average 227·8 grains of copper, 1480·5 grains of iron as FeO, 33·65 grains Fe_2O_3, 1380·9 grains of sulphuric acid, and 11·22 grains of arsenic; hundreds of thousands of gallons are passed per day, and, by the affinity which copper has for iron, a rapid galvanic action is set up, the free acid attacking the iron, giving sulphate of iron, and the copper taking the place of the iron in a metallic state. The liquor, when rendered of its copper, passes out of the service with 0·841 grain of copper per gallon, 1811·4 grains of FeO, 1331·9 grains of sulphuric acid, and 5·748 grains of arsenic; the copper is therefore almost all precipitated, the iron increased, and the ferric sulphate turned to ferrous sulphate, at the expense of the metallic iron. A small portion of the free acid is used in the precipitation of the copper and about half the arsenic is precipitated. Each day a certain length of the canals is cleaned, the pig-iron is lifted out, the metallic copper scraped off, and the iron replaced; a "cleaner" can despatch on an average thirty-four lineal yards of canal per day. The precipitate is loaded into wagons, taken to a yard where it is washed with fresh water, being drawn by large hoes against a running stream, the heavier grains and scales reaching the top of the washing canal, the finer grains passing on with the water to a depositing canal where they settle according to gravity, the lighter portion being deposited in a series of tanks adjoining the canal. In this manner an economical classification is made automatically. The next operation consists of throwing the scales into heaps and drying, after which they are ready to be sacked for export; the larger grain precipitate is pressed into cylinders of 22 lbs. weight, and, when dry, also sacked, whilst the poorer class deposited in the tanks is made up into heaps and burnt. By this arrangement the large portion of the arsenic, which is extremely injurious to the quality of the copper, is concentrated in the calcined precipitate. The foregoing

classification produces in relative proportion 72 per cent. of scales, 12 per cent. of cylinder, and 16 per cent. of calcined; the scale precipitate containing 92·5 per cent. of copper, the cylinders 78·5 per cent., and the calcined 48·3 per cent., the average contents being 81 per cent. of copper, with 2·80 per cent. of arsenical ferric oxide, the residue of 16·20 per cent. being graphite from the pig-iron, silica, etc.

The amount of iron consumed in the precipitation of the copper is about 1·25 time that of the copper produced; this is considered a very favourable result, although, according to theory, 56 parts of iron should precipitate 63·5 parts of copper, or in the ratio of about 8 to 9. This result, is, however, never attained in practice, owing to the ferric salts which are always present, as also the free oxygen which is relatively in large proportion in weak solutions such as are used, and tends to oxidize the iron; the arsenic also requires for its precipitation about 1·5 per unit, whilst the pig-iron itself generally contains not less than 6 per cent. of impurities. The whole of the liquors before entering the cementing plant are measured and analysed, a record being kept of the total amount of copper produced according to the liquors received. This serves two objects; first, the production of the month is known before it is possible to ascertain it by the actual copper produced, as generally three weeks elapse before the precipitate is dry and ready for export; and secondly, should there be more than one source from which the copper is derived, by the aid of the measurements and analysis it can be credited with its due amount. The company produces annually between 10,000 tons and 11,000 tons of fine copper.

Railway and Pier.

The main establishment at Tharsis and the port of embarkation are connected by a railway of 4-foot gauge, having ordinary web and flanged rails of 60 lbs. per yard spiked to the sleepers. Six to eight trains run daily according to the requirements of the shipping, each train carrying 100 tons of mineral, whilst an up and down passenger service is also worked in combination with the mineral trains. Each locomotive weighs 25 tons, and the entire journey of 29 miles occupies two hours. The cost of working the service is ½*d.* per ton of ore per mile, the line being kept in efficient working state by the employment on the maintenance of one man per mile of road.

The pier is an iron structure, 2,624 feet in length, having at its head ample berth for three vessels; it is provided with turn-tables

and steam cranes, the whole being equipped for the loading of 2,500 tons per day if necessary. Near to the pier is a storage-ground capable of holding 30,000 tons of ore, by the assistance of which the loading of the vessels is carried on continuously, there being no necessity to wait for down trains. During any reduction of shipping the excess received from the mines is tipped into the deposit, thus enabling either a large or small tonnage to be supplied to the pier-head for shipment, and a regular train service to be maintained; should also any serious breakdown occur there is always between 20,000 tons and 30,000 tons of ore to draw upon during repairs; contingencies are therefore amply provided against.

LABOUR.

The number of persons employed at the mines, on the railways, pier-head, etc., is, including men, women and boys, about 3,500. The average working day is eight-and-a-half hours, and overtime is of exceptional occurrence. The following are the wages paid for the different classes of labour:—

	s.	*d.*
Underground miners	3	0
" fillers	2	6
Opencast miners	2	6
" fillers	2	2½
Masons	3	0
Carpenters	3	0
Ore washers	2	0
Canal cleaners	2	9½
Mechanics	4	0
Engine drivers	4	0
Blacksmiths and fitters	3	6
Labourers	2	0
Mule drivers	2	6
Boys	1	2½

TREATMENT OF ORE IN ENGLAND.

The exported ore is shipped to Cardiff, Newcastle-on-Tyne, Glasgow and other ports, where it is treated by the alkali makers for the production of sulphuric acid; it is then returned to the works of the Tharsis Company at these ports, where its copper, silver and gold are extracted, the residue being sold as iron ore. The calcined ore, as received from the chemical manufacturers, is first tested for sulphur, which should, for facilitating the operation, exceed that of the copper contents by about ½ per cent.; when less an addition is made of unburnt pyrites. On obtaining

the due proportion of sulphur the whole is passed through a crushing-mill, during which operation 14 per cent. of salt is intimately mixed, more salt being added if there is an excess of sulphur above the required proportion. The mixture is then recalcined in muffle furnaces in charges of 3½ tons, which require about ten-and-a-half hours each for the completion of the reaction. The fumes from the furnaces contain copper, silver and gold, and are therefore passed up condensing towers containing coke, through which water is constantly dripping; the fumes are in this way freed of their valuable metals, and the towers are cleaned once every six months, the coke being specially dealt with. The flues also contain a fine powder which is separately dealt with for its metals, being first washed with acidulated water from the condensing towers which extracts the copper, the remaining portion being mixed with the precipitate from the silver settling vats. On the completion of calcination the ore is removed to a series of wooden tanks in which it is washed with (preferably warm) water, occupying about twelve hours, and the final or tenth washing is given with the acidulated water from the condensing towers, which removes the remaining copper so completely that hardly a trace is observable upon the spades which the workmen use in emptying the tanks. The liquors, as they are run off from the washing tanks, are allowed to flow into settling vats, and to others of slightly larger capacity; at the same time, from a specially graduated tank, together with a quantity of fresh water equal to one-tenth of the volume of the copper solution under treatment, an exact amount of a soluble iodide necessary to precipitate the silver present is run in. During this time the liquors are kept constantly stirred to ensure mixture, and are afterwards allowed to settle during forty-eight hours, after which time the supernatant liquors are assayed and run off into the copper precipitating vats, where the whole of the copper is thrown down by iron. The silver precipitating vats are cleaned once a month, and the precipitate collected at the bottom is washed into a vessel prepared for its reception.

The precipitate is composed chiefly of lead sulphate and chloride which is equal to about 40 per cent. of the whole, silver iodide and subsalts of copper. The latter salts are readily removed by washing with acidulated water, and the residue is decomposed by metallic zinc, which results in a precipitate rich in silver, containing a small proportion of gold and zinc iodide, which is again employed for precipitating when its strength in iodine is ascertained. The cost of the iodine is about 9*d*. per oz., 13 per cent. of which is

lost, whilst 70 per cent. of the total silver in the ore is recovered and 40 per cent. of the gold, the cost of the extraction of the gold and silver being between 8*d.* and 9*d.* per ton of ore. Few tests are made during the progress of the work, but the whole operation is most delicate and requires constant skilled attention. The copper precipitate produced, as well as that received from the mines, is smelted and refined in the works.

The Paper is accompanied by two tracings and three photographs, from which the *Figs.* in the text have been prepared.

APPENDIX.

RAINFALL AND EVAPORATION AT THARSIS MINES.

Year.	Rainfall.	Evaporation.
	Inches.	Metre.
1881	36·24	..
1882	14·15	..
1883	25·16	..
1884	25·12	..
1885	41·14	..
1886	21·11	..
1887	31·91	..
1888	36·39	..
1889	16·60	1·57
1890	23·70	1·65
1891	21·08	1·63
1892	35·08	1·50
1893	27·74	1·53
1894	28·01	1·45
1895	46·02	1·35

(*Paper No. 2933.*)

"Tin-Smelting at Pulo Brani, Singapore."[1]

By JOHN McKILLOP and THOMAS FLOWER ELLIS, A.R.S.M.

THE deposits of alluvial tin ore in the Malay States have been for many years, and will probably long continue to be, the chief source of the metal. These deposits, as well as those in the adjoining countries of Siam and Southern China, have, during three centuries, been worked by the Chinese, and to a less extent by the Malays and Siamese.

Until recently the ore was smelted by the Chinese in a most primitive manner; charcoal or half-charred wood being used as the reducing agent in small clay cup-shaped furnaces, with a blast furnished by a sort of air-pump made of wood and worked by hand. This method of smelting is still largely practised, though it is probable that before long it will be abandoned. Its continuance depends partly on the cheapness of Chinese coolie-labour, and partly on the absence of adequate regulations for the preservation of forests in the Malay States. Such regulations are however being now adopted by local governments in the Malay Peninsula. The enactment of these, or any other cause for an increase in the price of charcoal, would undoubtedly render the Chinese tin-smelters unable to compete against the more refined and economical method of smelting with coal and anthracite in reverberatory furnaces.

To the Straits Trading Company belongs the credit of being the first European company to compete successfully against the Chinese in tin-smelting. In 1885–86, one or two agencies were established in the States of Selangor and Sungei Ujong, and, in the teeth of fierce opposition and prejudice, some of the native miners having been induced to sell ore, smelting operations were begun at the abandoned works of the "Shanghai Tin Mining Company of Perak" at Teluk Anson on the Perak River. It was subsequently decided to build works in or near Singapore, as the

[1] The discussion upon this communication was taken in conjunction with the two preceding Papers.

experience gained at Teluk Anson showed conclusively that the drawbacks to successful work in such an outlying spot were too serious.

The site chosen at Singapore was that formerly occupied by a graving-dock and accessory works on Pulo Brani, an island lying south of Singapore Island and west of the town. It is reached from the business part of the town by a drive of 3 miles and a ferry of about ½ mile. The island is about 250 acres in extent; and the channels by which ships approach it are fairly easy to an experienced pilot. The chimneys of the works form a conspicuous feature of the view on entering the harbour from the west, and will have been noticed by any one who has visited the capital of the Straits Settlements in the last eight years. Smelting at these new works was begun in December, 1887, with one 2-ton furnace, and has continued ever since. The works rapidly increased in extent, and at the end of five years practically covered 8 acres. They now consist of twelve 4-ton furnaces with accessory plant.

General Arrangement of the Works.—The ground plan of the works is shown in Fig. 1, Plate 3. Everything, with the exception of the European quarters and part of the refinery to be afterwards explained, is on one level—6 feet to 8 feet above high-water. The ground sloped naturally to the sea-front, and a good deal of cutting and filling has been done at various times to level the place. The high ground at the back, 20 feet to 25 feet above the works level, is reserved for European bungalows. Coal-ships and local steamers lie alongside the wharf, and lighters discharge ore, etc., from the dock direct into the ore-room.

The sheds covering the furnaces, machinery and coal-sheds have light iron roofs covered with galvanized iron and carried on iron columns. The store and mixing-room is a brick building about 250 feet long by 50 feet wide. The refinery and metal store are similarly built. The bungalows for Europeans are of wood, surrounded with wide verandahs and carried on brick piers. The huts for the coolies are light wooden buildings carried on wooden posts, covered with the thatch of the attap palm—a style of building suitable to the climate and to the habits of the natives. The blacksmiths', carpenters', and other workshops are wooden sheds covered with attap. The superior native servants, mostly clerks and weighmen, have each a brick house, two storeys high, built in the local style with an air-shaft in the centre.

Buying and Handling Ore.—By far the greater quantity of ore landed on the wharf of the works is bought by the Company's officers at various agencies in the native States. Both at the agencies and at the works the value of the ore is determined by

cyanide assay. If it contains much impurity, the sample is first boiled in aqua-regia, and is occasionally vanned. From the appearance and hardness of the assay button obtained, no less than from its weight, the agent fixes the price he will offer. When bought, the ore is sometimes further dressed at the agencies by various devices. The comparatively small quantity to be treated renders any other than manual power impracticable. Hand-jigging and sluicing are the methods usually adopted, yielding ore of high quality and rich tailings. Fortunately natives can be found to work these tailings over again with infinite pains in a "dulang," or wooden dish similar to the Australian miner's dish, but larger and not so deep. The ore is afterwards dried, packed in canvas or jute bags, labelled, and sent down with a guard to the nearest port, where it is shipped direct to Pulo Brani. The ore, when landed, is carried to the store, weighed and stacked under cover by coolies, under the supervision of a weighing-clerk. The assayer then samples and assays each parcel, and his report determines the subsequent treatment. Those lots which need to be roasted are stored in the roasting-house, while the clean ore is emptied into bins in the mixing-rooms. The cost of the bags is a very serious item. When emptied of ore they are taken to a separate room, cleaned, dried, repaired, packed into bundles of one hundred each, and sent back to the agents.

Great care has to be taken in handling the ore. 5·97 cubic feet weigh 1 ton. As it is worth £40 per ton upwards, it can be easily imagined what great loss would accrue from careless handling. Cast-iron floors would undoubtedly be the least wasteful but for the great initial expense. Concrete covered with cement was tried, and did well where there was no wheel traffic; the barrows, however, broke it up in six months. The best floor tried was made of wooden blocks boiled in tar and arsenic, and laid as close as possible, without other joint than that formed by the excess of tar.

Preparation of Impure Ores.—The production of good marketable tin depends greatly on the quality of the ore smelted. It is true that a great deal can be done to improve bad metal by subsequent refining, but the results are never really satisfactory. The true way to avoid producing tin of inferior quality is to strike at the root of the evil, and eliminate all injurious impurities from the ore before the furnace is charged. The smelter should throw as much of this duty as possible on the miner. At Pulo Brani a sliding scale is used, by means of which the price paid for the ore depends not only on the metallic tin it contains, but also on the nature of the impurities present. The chief of these are

mispickel, copper pyrites, and iron pyrites. Wolfram, though never entirely absent, is not present in sufficient quantities to render profitable its extraction as tungstate of soda, by the Oxland process. Its chief effect, as also that of the various siliceous and titaniferous impurities, is to cause loss of tin by increasing the richness of the slags. An incredibly small quantity of arsenic, sulphur, or copper in the ore is sufficient to render the tin produced from it useless for all purposes except that of manufacturing inferior solder. At Pulo Brani, any ore containing arsenic or sulphur is thoroughly roasted at least once. The furnace is of the "blind roaster" type, the ore being in a muffle out of direct contact with the fire. The flame from the fire-box passes first between two arches over the bed and then under it to the flue. During the roasting, the ore is rabbled through the charging-doors along the side of the chamber, a suitable flue taking away the gases and fumes evolved. It is found practicable and cheap to roast when necessary in an ordinary smelting-furnace, logs of mangrove wood being used as fuel, and plenty of air being allowed to pass through the doors of the fireplace.

When roasted, the ore, unless of very poor quality, in which case it is treated with tailings, is sluiced by Chinese coolies, and gives "good headings," which can be smelted directly; "coarse tailings," which need to be crushed; and "fine tailings," which are caught in boxes at the tail of the sluices. The "coarse tailings," after being stamped in a 5-head Californian stamp-battery, are again sluiced. The headings therefrom are re-roasted, and treated on a set of six Frue vanners; while the tailings, together with the fine tailings from the first sluicing, are treated separately, being first somewhat concentrated by passing through a set of fixed buddles, then again roasted and passed over the Frue vanners. Some eight sluices are constantly worked. The stamps are also looked after by Chinese coolies, whilst the buddles and Frue vanners are tended by Kling or Madras coast coolies.

Although this is the general procedure, it is varied greatly according to the nature of the ore. Ore containing copper is allowed to stand for a considerable time between the roastings, to weather as much as possible and to allow the copper sulphate to drain off. Both machine and hand-jigs were largely employed at one time, but the latter proved too expensive to be continued, though they gave excellent results so far as purifying the ore was concerned.

System of Labour in Mixing Charges.—It is usual in tin-smelting works for the charges to be mixed by the furnacemen. This is not a good plan under any circumstances, and it is impracticable

where the furnaces are worked by Asiatic coolies. At Pulo Brani all work that can possibly be so arranged is paid by piece. The coolies work under the direction of a contractor, subject to a Chinese clerk to whom the manager delivers his orders in writing, and who is responsible for the weighing and mixing.

The manipulation of the ore is divided into three sections—(1) Discharging from a steamer at the wharf or from a lighter in the dock, weighing, storing, emptying into bins or placing the bags at the roaster, or in the concentrating-shed. This is the work of one gang paid at schedule prices. (2) Mixing; this is the work of a second gang, who have to take the ore and other materials, weigh and mix them, and place the charge in a bin in the charging-room, ticketed to show its destination, at a fixed price per ton. (3) The third stage is the work of a distinct set of coolies, who wheel the charges from the charge-bins to the furnace-door, and leave them ready for the furnacemen to put in. Metal from the furnace to the lighter is treated similarly.

An outline of the detail work of charge-mixing is as follows:—The bins each contain ore of a certain assay value; the day's orders contain directions for mixing the charges by taking so much ore from each bin, in order to keep the assay of a charge constant at a given figure. Welsh anthracite is used as a reducing agent; and drosses, sweepings, skimmings, &c., have to be mixed in ore charges in such ratio as to keep them down in quantity and prevent accumulations.

The Smelting Furnaces.—The furnaces, Figs. 2–9, Plate 3, at Pulo Brani are of the ordinary reverberatory type. There have been many alterations in them, however, from the pattern originally erected in 1887. The distinguishing feature of the latest furnace is the water vault. Tin at high temperature becomes very fluid; and this property, together with its comparatively high specific gravity, renders it a most difficult matter to prevent leakage. After many trials and attempts to entirely prevent leakage through the bed, all of which failed, it was decided to regulate the leaks rather than to try to prevent them. The evil of these leaks is not absolute loss of metal, but trouble and difficulty in recovering it. Tin melts at 260° C. The foundations of a furnace, and the ground around it, are at or above this temperature for a distance of some feet. Consequently, any tin that leaks into the vault of an ordinary furnace below the bed remains liquid, and will slowly but continuously find its way through the cracks of the ground until it reaches a place where the temperature is less than 260° C. The distance tin will travel is incredible to those

who have not seen it. The cost of the periodical recovery of all this metal is very great; for the metal is either in huge lumps of 10 tons or more, or else in fine strings and sheets into which it has been moulded by cracks in the clay. Sand is said to form an effectual bar to the passage of melted tin. The experience of the Authors is that at comparatively low temperatures it does act as a check, but at higher temperatures the tin and sand become mixed so completely that separation by heat is very wasteful owing to the oxidation of the metal. Further, anything siliceous round a tin-furnace should be avoided as far as possible. It will have to be swept up and treated in a furnace sooner or later to extract the tin; and the more silica it contains, the greater will be the quantity of slag produced, and consequently the greater the loss of tin.

This loss of tin by leakage, with attendant difficulties in recovery, have been entirely overcome by the introduction of the water-vault, below the bed, containing a depth of 8 feet of water. Any drops of tin are granulated in this water and their further passage is effectually checked. Once a week the water is pumped out and the granulated metal is recovered. In every case in the Authors' experience, such explosions as have occurred have been due to deficiency of water. If care be taken to rabble down any heaps of granulated metal which form below the water, and if the water-level be maintained, no explosion of a serious nature can occur.

The bed and lining are the most important parts of the furnace, and the most difficult to keep in order. It is necessary to build the furnace in such a way that the bed, lining and roof can each be repaired or replaced without disturbing the other parts. The bed is of fire-bricks laid on end. In order to reduce the joints as much as possible, the faces of the bricks are ground true before being laid. They are laid dry, and forced tight with screw-jacks. The rails which carry the bed lie across the furnace, and are divided in the centre. Here they are carried by a strong iron rail, while their other ends rest on the inner 4½ inches of the wall of the furnace. The large rail is carried at each end of the bed on smaller rails built into the brickwork, or by pillars built up from the floor of the vault. Both methods possess advantages. The large rail is divided in the middle, and is there carried by a pillar. The bed is laid with a fall of 3½ inches to the tap hole from every part of the furnace. This fall is secured by placing the rails accurately in position, the bricks following them. The large rail is first placed accurately along the centre-line of the furnace, with

a fall of $1\frac{3}{4}$ inch from the front door and bridge. The $4\frac{1}{2}$-inch work which carries the small rail round the charging-door side is levelled; while that round the tap-hole side is finished with a fall of $3\frac{1}{4}$ inches from the bridge and front door to the tap-hole. The cross rails can then be placed in position and the bricks laid. Sometimes the large rail, instead of being divided at the middle, is merely heated and bent. This is very troublesome and has no advantages over the method of dividing the rail. When a bed is worn out, it can be quickly removed by knocking down the centre pillar, when the whole collapses. The courses of bricks in the bed are laid across the furnace, beginning at the bridge. One course is laid at a time, and is carefully keyed up while the screw-jack is on. The bricks are all gauged for each course, $\frac{1}{16}$ inch excess or defect on the width ($4\frac{1}{2}$ inches) being rejected. When the bed is complete it is grouted with fire-clay cream, dried carefully and heated. The first charge is cast-iron, which, when melted, forms an excellent grout and binds everything firmly together.

The lining rises from the red brickwork behind the bed. The end brick of each course of the bed abuts on the lining, which must therefore have a true face and the smallest possible joints. The lining is all in headers. Where it meets the roof it is finished off by a course of three-corner end-splayed bricks. The roof, instead of springing from the lining, springs from the outside work of red brick. As this is only $1\frac{1}{2}$ brick thick, the thrust of the roof is taken by T-iron, built in and supported by the vertical girders which bind the furnace. The thrust of the bed of the furnace is taken in the same way by T-iron built into the brickwork. The bridge is built with as much care as the bed. It cannot, however, be kept tight, and is therefore built with a cavity which is continuous through the outside work. In this way any slag which leaks through and sets can be knocked off with a steel bar. Tin which leaks through the bridge falls into the water in the vault. The doors of the fireplace are in the back wall opposite to the bridge and high up. The fireplace is easily filled through these doors, and the fire-rabble is rarely needed. The coal lies at its proper angle of repose from the roof above the fire-doors down to the bridge, and there are no empty corners possible. Winding is done through a cast-iron winding-plate placed below the fire-doors. The lower row of holes in the plate is about 9 inches above the bars. This form of fire is very easily worked. The "flote" or pot into which the metal runs when the furnace is tapped is a wrought-iron or steel tank lined on

the bottom with 9-inch, and round the sides with 4½-inch fire-brick. These leak in spite of all efforts to keep them tight, and the water-vault has been extended under them with good results. In case of any hot material getting through the bed with a rush, two pipes, 18 inches in diameter, are built into the thick corner of the furnace in order that the steam may escape freely.

The working of the furnace is as follows. Suppose a charge has just been drawn. The doors are open and the bed and walls are inspected. If much worn and eaten away they are "fettled." A mixture of bauxite and fireclay moistened with water is put on the worn place with a paddle, and is rammed home with the head of a rabble. When all the bad places are covered, the doors are lowered and the fettling is "glazed" by hard firing for about an hour. This fettling should be required only once a week, in addition to that given when the furnace is overhauled on Sundays. When the furnace is hot and ready, the doors are opened, the damper is closed, and the charge is thrown on the bed through the side doors, while the leading coolie levels it with a rabble through the front door. The charge being all in, the doors are closed and the fire is made up as large as possible. Meanwhile the charge-wheelers bring out the next charge and tip it under the charging-doors, and one of the four furnace coolies turns it into two heaps, one under each door. The leading coolie then turns his attention to the slag-beds, and prepares them to receive the slag from the charge. As soon as he sees that a fresh fire is needed, he calls the European smelter, who, after inspection through the peep-hole in the front door, decides whether to put on another fire or to rabble the charge. With good coal the first fire should last two hours or longer. This gives the charge a proper start, after which it may be rabbled. It should be liquid near the bridge, and only moderately thick at the tap-hole, where it is deepest, and towards the front door, and frothing freely all over. A good rabbling at this stage should free it from the bed, and mix it thoroughly. The fire is again made up as full as possible, and when it has burned clear the rabble is again used to ensure that everything is loose from the bed. At this time the surface of the charge in the furnace should be resplendent and free from floating lumps and patches. If so, the door is closed, another fire is put on, and the tapping-bar is withdrawn. A stream of tin ¾ inch in diameter escapes and falls into the flote. At this rate it requires about forty minutes for all the tin to drain out, leaving only liquid slag in the furnace. When it has been ascertained that all the tin is out, the tapping-bar is again inserted, and the channel from

the tap-hole is altered to deliver over the slag-beds. The whole of the clay stopping of the tap-hole is removed, and the slag, rushing out, fills the slag-beds. The tap-hole is then closed, and the furnace is recharged.

Metallurgical Processes.—The metallurgical processes employed may be conveniently considered in four parts.

(A) Smelting ore, with the production of "rich" slag and "ore metal"; (B) Smelting rich slag, with the production of "poor" slag and "rough metal"; (C) Treatment of poor slag containing tin as prill; and (D) Refining the metallic products of (A), (B), and (C).

(A) A charge is made up by mixing ore with between 13 per cent. and 15 per cent. of culm or anthracite, and about 3 per cent. of refinery dross. If the quantity smelted at one time is 4 tons, the composition of the charge would be somewhat as under:—

—	Poor Ores, 65 per Cent. and upwards.	Rich Ores, 71 per Cent. and over.
	Cwt.	Cwt.
Ore	80·0	80·0
Culm	10·4	12·0
Dross	2·4	2·4

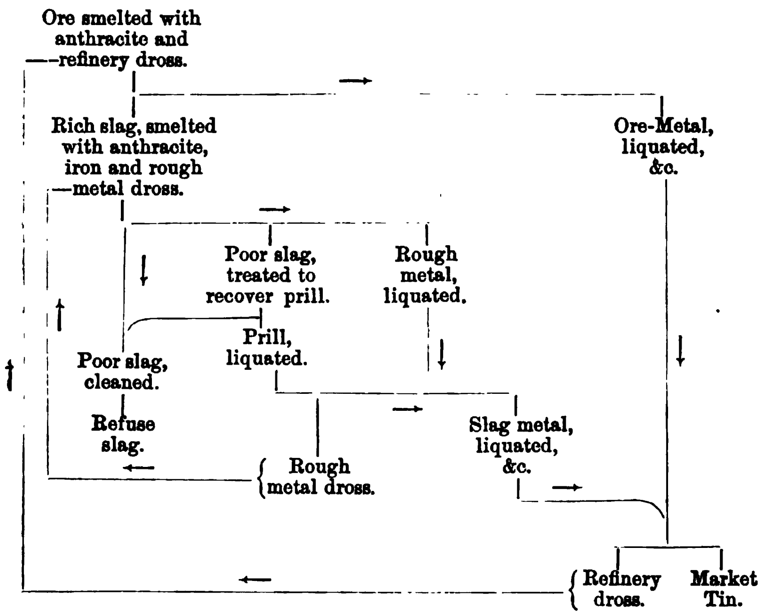
The time required for a charge should be seven hours or eight hours with good coal and labour, but sometimes longer periods are required. From a charge of such composition there should be obtained 45 cwt. to 48 cwt. of metal containing about 99·5 per cent. of tin, and 29 cwt. to 30 cwt. of rich slag containing 30 per cent. to 40 per cent. of tin.

The metal from these charges is hard, brittle, and dull in colour; it is rather greyer than refined tin, and if poured hot, it may be covered with beautiful iridescent films of oxide.

The slags produced at this stage, distinguished as "rich slags," are variable in appearance—sometimes dark brown and highly crystalline, and sometimes quite black and glassy. In thin sections they show under the microscope a yellow matrix with numerous black crystallites. Reflected light shows tin prills and at times a brown substance, probably ore that has only been fused. Their composition varies widely. Specimens examined contained 35 per cent. of tin, 15 per cent. of silicon, 18 per cent. of aluminium, and 9 per cent. of iron, in addition to manganese, titanium, lime and magnesia.

(B) There are many ways of smelting rich slag. They may be tabulated as follows:—(1) Smelting rich slag with excess of scrap-iron and culm to produce "hardhead" and poor slag unfit for further use. This method alone is not desirable, as the hard-head produced (an alloy of iron and tin very difficult to separate) is difficult to treat further. (2) Smelting rich slag with culm and sufficient iron to decompose the tin silicate. The difficulty with this method is the danger that the slag produced should be too rich to throw away; but the metal (termed "rough metal") is fairly

DIAGRAM SHOWING THE PROCESSES OF SMELTING.



soft and not difficult to refine. (3) A combination of the first two methods, by which hardhead is first produced by excess of iron, and is subsequently smelted with more rich slag; the result being that the rough metal is fairly easy to refine and the slags are sufficiently poor to be rejected. The process, however, requires great care both in mixing and smelting.

In refining the metal from slag, whatever process is employed, a heavy black dross always remains, containing iron oxide and tin oxide. This is called "rough metal dross," and has to be worked up continuously. The two following methods of working slag are therefore also used:—(4) Rich slag is smelted with culm and

rough metal dross, producing rough metal and poor slag—a process which also requires great care—or (5) Rough metal dross is used to replace hardhead in process (B) (3). The greatest objection to all these and similar processes is their intermittent nature. Continuous and regular work is most desirable in metallurgical as well as in other industrial processes.

The mixings required for the above processes are respectively as follows:—(1) 1½ ton of rich slag per charge mixed with 20 per cent. to 27 per cent. of iron and 23 per cent. to 26 per cent. of culm, according to the richness of the slag; (2) 1½ ton of rich slag with 16 per cent. to 20 per cent. of iron, and 20 per cent. to 25 per cent. of culm, according to the richness of the slag; (3) 1½ ton of rich slag with 62 per cent. to 70 per cent. of hardhead and 24 per cent. to 25 per cent. of culm; (4) 1½ ton of slag with 62 per cent. to 70 per cent. of rough metal dross and 20 per cent. to 24 per cent. of culm. A 1½-ton charge should be smelted in a furnace similar to that described for smelting ore.

In all the foregoing methods of extracting tin from slag, iron is used, and there is difficulty in ensuring that the exact quantity may be used so that pure tin and pure iron silicate may be obtained. The result always is, that to get a silicate of iron approximately free from tin, excess of iron has to be used, which alloys with the tin, giving rise, when the tin is refined, to rough metal dross. Therefore some of the iron added to the rich slag is lost as silicate and some returns as rough metal dross. If then the ratio of these two quantities be found, the slag may be smelted with rough metal dross and iron in such quantity that the amount of rough metal dross obtained from a charge and added to the charge is equal and constant, while the iron added is just equal to that thrown away as silicate.

The quantities are thus found to be:—Slag, 30 cwt.; dross, 6·5 cwt.; iron, 2·75 cwt.; but the slag resulting from this rational composition of the charge was too rich. An addition of rough metal dross led to the disappearance of this trouble, and the proportions adopted were:—Slag, 30 cwt.; dross, 12 cwt.; iron, 2·75 cwt. The excess of rough metal dross can do no harm, as it only circulates unchanged. In addition to these constituents culm has to be added. Slag is ferrous silicate, and a reducing action must take place simultaneously with the replacing action. Coral or lime in any form is also added as a flux to combine with some of the silica present. It is easy to add too much, in which case it combines with the oxide of tin present, and carries it into the slag.

The final composition of the charge would be, therefore, slag, 30 cwt.; dross, 12 cwt.; iron, 2·75 cwt.; culm, 6 cwt.; coral, 2·4 cwt. This method of smelting slags gave satisfaction in every respect. The details of the process are similar to those given under ore smelting. In smelting slag, however, though the furnace and fuel may be the same, a much higher temperature is attained than when ore is smelted, the duty of the fire being less. It is safe to assume that, in ore smelting, the chemical change represented by the equation $SnO_2 + 2C = Sn + 2CO$ takes place to some extent, and this, being an endothermic reaction, may account for the lower temperature of the ore furnace as compared with the slag furnace, other things being constant. Whatever may be the reaction that takes place with slag charges, it is but slightly endothermic compared with the reaction between the ore and carbon.

A slag charge is rabbled three hours after charging, and again an hour later, by which time the charge ought to be well off the bed and the rough metal ready for tapping. The reaction between the slag, iron and culm takes place with considerable violence. When the frothing and bubbling has ceased, the charge is again rabbled, the rough metal is run into the flote, and the slag into moulds. A slag charge should not require longer than between six-and-a-half hours and seven hours.

The products of melting slag are "second," or "poor," slag, and rough metal. The poor slag obtained is hard, black and glassy. In thin sections under the microscope it shows here and there a small amount of yellow matrix; but it seems to consist chiefly of a dark black crystalline body with the crystals closely packed together. It varies greatly in composition, containing 60 per cent. of silica with varying amounts of other bodies that are also found in the rich slags. This slag contains numerous lumps and prills of tin. The lumps are removed by hand-picking after the pigs of slag fall to pieces. The finer prills are recovered as described subsequently, (C). The rough metal is ladled from the flote into moulds and is stirred, while liquid in the moulds, with an iron rod. This stirring is most important, as otherwise the ingots would tend to set in two distinct layers, the lower and larger portion being practically hardhead, an alloy having a high melting-point, while the upper layer would be nearly all tin, holding a little iron in solution. The same result is attained by granulating the metal. In both methods the metal is constrained to set as a uniform alloy, or mixture of two alloys, and is much more capable of economical liquation in the subsequent refining.

The metal is black and dirty in appearance; it is very brittle and the fracture is steel-grey.

(C) The recovery of the prill may be effected in two ways; (1) by crushing and washing it, as is the practice in Cornwall, and (2) by "running" it in a furnace. The first method was tried at Pulo Brani, but was abandoned, owing to the large amount of the metal reduced to slimes, and rendered difficult of recovery. Slag metal, as pointed out above, is very brittle, and hence it easily forms slimes. The second method is more effective and not more expensive. It consists of re-melting the slags and allowing the metal to sink to the bottom of the liquid charge. It is not necessary to treat all the second slag in this way. By making the first two moulds in the slag-bed deeper than the others, practically all the metal which does not run into the flote can be collected in these moulds; and the slag in the remaining moulds (more than two-thirds of the total quantity) can be thrown away as clean. This leaves less than one-third of the slag to be treated. In this process no chemical change has to be effected; a given mass has merely to be melted and then run off; consequently, the amount of fuel of required is not large.

The charge is rabbled two hours and again three hours after charging, after which the slag only is run off. About three times in the week, the metal which has collected on the bed is tapped off, by giving the furnace another fire after the slag has been tapped; the metal produced being run into sand moulds, and broken up to convenient-sized lumps while still red-hot. This is necessary on account of the extreme toughness of the hardhead when cold; when it is hot there is no trouble in breaking it up. The metal can, however, be treated in the same way as other rough metal, and stirred in the moulds or run into water. A charge would contain, slag, 40 cwt.; culm, 2·5 cwt., and coral, 2·5 cwt. If the slag is free from combined tin, the coral and culm may be omitted. They are only added to effect a further reduction of any combined tin in the slag. Four hours is a full allowance for treating these charges.

(D) Liquation is the method principally adopted for refining at Pulo Brani; but "boiling" is sometimes resorted to under special circumstances. The ingots, or granulated metal, are piled in a furnace heated to incipient redness, wood being used as fuel. Metal which has not been stirred in the moulds, or which has not been granulated, when thus treated, would leave behind large lumps of hardhead in place of the powdery rough metal dross. The products obtained from liquating rough metal, if properly

conducted, are about 90 per cent. of "slag-metal" containing 99·5 per cent. of tin, and 13 per cent. of rough metal dross, containing about 65 per cent. of tin, and 25·5 per cent. of iron, partly as oxides and partly as alloys. This dross is mixed into the slag charges, as has been shown, and circulates in constant quantity.

The metal from this liquation is of about the same composition as "ore metal," and its further treatment depends on its destination. For ordinary commercial tin, suitable for making tin plates, solder, or for use in galvanizing, it would be mixed with ore metal, and the two finally refined together. Tin required for making foil or for chemical salts must be very pure and free from iron. It is best in making this quality to avoid any mixture of slag metal, but, if this cannot be avoided, the slag metal must be boiled before it is mixed with ore metal, or the mixture must be boiled after the second liquation.

Boiling is usually performed only on such ore and slag metal as has been derived from ores that have needed roasting and dressing. It consists merely in immersing logs of green wood in the molten metal. The tin is kept just above its solidifying point by a small fire under the kettle. The operation lasts for several hours, until the bubbles of steam from the wood cease to bring scum to the surface of the tin. The wood is then lifted out, and the metal is skimmed, ladled into moulds, and sent to the refinery, the skimmings being added to the slag charges.

The slag metal is then fit to enter the refinery. This building is shown in Figs. 10, Plate 3. The operations performed in it are liquation, followed by "tossing," which consists in allowing molten tin to fall from a height into a mass of liquid metal, thereby carrying air into the mass and permitting a certain amount of oxidation. The liquating-furnace is a rectangular chamber with a fire at each end; the smoke leaves by a chimney in the centre of the arch. The ingots are piled on the bed and wood fuel is used. The tin runs continually through the open tap-holes of the refining-furnace into the two kettles A and B (Figs. 10, Plate 3) which are situated in the pouring-room. These two kettles are about 3 feet 6 inches in diameter, and are each capable of holding 7 tons of tin. From these kettles the metal is ladled into one of the larger kettles C, D, E or F, each of which is 8 feet in diameter and holds 30 tons of metal. The kettles A and B are about 2 feet above the others, so the metal in falling into the latter is well stirred and aerated, the average fall during the filling of the larger kettles being not less than 4 feet. In these

latter the metal is allowed to stand for twenty-four hours, after which it is skimmed and poured into moulds. When cool, the ingots are weighed, and are then stored ready for sale in the ingot room, whence they can be readily loaded into boats at the small wharf. The tin is kept liquid in the kettles at a temperature of as nearly as possible 260° C. On standing, nearly all the remaining impurities settle out from the tin to the bottom of the kettles, and for this reason the bottom 12 inches or so of metal remaining in the kettles is sent back to the refinery to be liquated again.

After liquation in the refinery furnace, the ingots of metal leave behind on the bed of the furnace a grey, powdery body. This substance is known as "refinery dross," and is taken to the mixing-room, where it is added to ore charges. One hundred parts of ore metal will give about 96·5 parts of fine metal and 4·5 parts to 5 parts of dross. Refinery dross is a mixture of the oxides of tin and iron with less easily fusible alloys of the two metals. It contains about 65 per cent. of tin and 11·5 per cent. of iron.

Marketable Tin.—Ingots of good tin should on cooling have a clear, bright surface, with a slight depression on the top, and the crystalline appearance of the surface should show a large pattern. The metal should be soft enough to be marked by the finger-nail, should bend easily, and, if partly cut and then bent, the strained surface should have a smooth, silky lustre, appearing rather as if it had been pulled out than either torn or broken. Impure tin will give the "cry" of tin on bending; but, on cutting and bending the brittleness of the fracture will increase with the impurity. The latter is the only test used by the buyers in the Straits Settlements. It is unsatisfactory, as the four corners of an ingot can be cut and bent so as to show four distinct qualities. The best test is to roll out a piece of the metal. Inferior tin will then show cracks along the rolled edges, and, if the rolling is fine enough, pin-holes will appear through the foil.

Tin, with as little arsenic as one part in 10,000, will break with a crystalline fracture; four parts in 10,000 will distinctly alter its appearance. The upper surface in an ingot of such tin is pitted, and has a frosted appearance. Small holes occasionally appear on its surface. Iron is always present in metallic tin, and it appears that the presence of this metal is to some extent advantageous. It remains to be discovered whether iron acts merely as a corrective to the other impurities present, or improves the ductility of the metal. It may be that in liquating, or in allowing the tin to stand when liquid for some time, the iron

assists the elimination of other impurities. Ore metal comparatively free from iron is improved by being mixed with slag metal relatively richer in iron. A case which seems to point to the same conclusion came within the notice of the Authors in a very striking manner. A large quantity of highly pure ore was smelted, the resulting tin being kept apart during the refining process, and offered separately for sale. The buyers refused to take it, the metal not satisfying the tests applied to it. Analysis showed it to be quite pure. Accordingly it was re-melted and mixed with some inferior metal, and the resulting mixture was bought directly as tin of the best quality.

Loss of Tin.—From the diagram, p. 154, it will be seen that from, say, 100 parts of ore, containing 70 parts of tin, 56 parts of ore metal are obtained in (A), which is sent to the refinery, and some 36 parts of slag, containing 12 parts to 13 parts of the original 70 parts of tin. As the dross from the refinery is sent back to the ore furnace, it may be considered that in the end the whole 56 parts will be obtained. In (B) and (C) the loss of tin commences, and depends upon the amount of poor slag produced, and its richness in tin. The latter may be taken on the average at 5 per cent., and, as 36 parts of rich slag produce about 27 parts of poor slag, the amount of tin thrown away as poor slag will be 1·35 parts, or nearly 2 per cent. of the tin started with. The loss by splashing and theft will bring it up to somewhat over 2 per cent. of the total amount of tin brought into the works. Considering the various refining processes (D), it is clear that when once the work is continuous no loss of tin would take place there; for the various drosses, as in the case of the refinery dross, are returned to the smelting-furnaces. This applies also in the case of the prill in the poor slag, which is returned from (C) to (B).

Consumption of Iron.—It will be evident that the iron added to the slag charges, viz., 2·75 parts in 30 of slag, or 9·17 per cent., is thrown away in the poor slag. Rich slag is about 36 per cent. of the ore, or 50 per cent. of the tin contained in the ore; therefore the consumption of iron is 4·7 per cent. of the tin obtained.

Consumption of Culm.—This amounts to about 17 per cent. of the ore smelted. If the action of reducing tin ore were exactly represented by the equation $SnO_2 + 2\,C = 2\,CO + Sn$, the culm required would be 18 per cent. Anthracite landed in Singapore is expensive, and experience has shown that coal of good quality may be used to replace it. It is necessary, however, to use about 10 per cent. more of the latter. Charcoal may be used, but it is very destructive to the furnace, especially to the flue and "verb,"

or entrance to the flue from the furnace. This is probably due to the potash and soda it contains.

Consumption of Fuel.—The coal used at first was chiefly Australian. Latterly this has been almost entirely replaced by Japanese coal, and still more lately, owing to the rise in price of the latter coal during the war, it has been replaced by coal from Labuan and the Tonkin coal-fields. As the wharves at the works allow ships of 3,000 tons to come alongside, the price of freight is not so high as might be expected, and, except during the wool and wheat seasons, freights are low. The varying cost of coal necessitated a large storage capacity at the works. The coal-sheds are capable of holding about 12,000 tons and even this quantity proved insufficient on one occasion. The consumption estimated on the average of many months' regular work, for all purposes (including boilers, blacksmith, &c.), in smelting ore averaging 68 per cent. net return, is 1·15 ton of coal to 1 ton of ore.

Future Improvements.—Considering the locality of the works described, and the difficulties consequent on the employment of native labour, their organization and management are fairly satisfactory, but numerous improvements in economy by using better mechanical appliances suggest themselves. Owing, however, to the low price of unskilled labour at Singapore, many improvements that would effect economy in Europe are hardly worth introducing in the Straits Settlements. The initial cost also of setting up plant and of repairs is much greater there than in England. The following improvements might be made with advantage. Overhead charging through a hopper would save considerable time with each charge. Allowing the slag to run into slag-trucks would, besides saving labour, prevent the introduction of silica from the sand-moulds into the slag-charges, and the consequent increase of the quantity of poor slags which are thrown away. The flote containing the tin from the ore furnace might be made movable, and means be introduced of automatically casting the ore metal into ingots. The rough metal might be granulated by allowing it to pass from the furnace into a deep well of water, and recovered from it by a cage lifted by a crane. In a granulated form rough metal will liquate excellently, and the ladling into moulds and the stirring are then rendered unnecessary.

A regenerative furnace of the Siemens type was tried, but proved unsuccessful, owing to the impossibility of keeping the chambers free from tin. The cost of repairs and minor alterations

inevitable at first were objections which proved too great for its extended use. The ease with which the furnace was worked and controlled, together with the economy in fuel, merited, however, a longer trial.

At various works in England tin slags rejected by the Cornish smelters are treated profitably, the tin being extracted in the form of solder. Lead in some form is, by a process devised by Mr. T. H. Heason, smelted with the tin slag. A sample from works of this kind in Cornwall was found still to contain more than 3½ per cent. of tin. The tin industry in that county seems to be suffering from the lowness of the price of the metal and the increased production in the Straits Settlements. Investigation into the matter might, however, reveal other causes for this depression. A sample of Cornish slag which was sold as road metal was found on analysis to contain more than 15 per cent. of tin.

The Chinese, as has already been mentioned, smelt their ores on an entirely different principle, using small blast-furnaces. Working as they do in a very moist atmosphere, a great deal of the reduction of the cassiterite in their furnaces seems to be effected by what is practically water-gas passing over the heated ore. As is well known, there is an analytical method of reducing cassiterite by heating it in a combustion-furnace and passing hydrogen over the ore. From these considerations, it may be supposed that an entirely new method of smelting cassiterite could be devised; and the future may yet show that the Chinese are working on a more economical principle than Europeans.

In conclusion, the Authors urge strongly on metallurgists how vast is the room for improvements in tin-smelting, perhaps the oldest, and certainly one of the most backward, of English industries.

The Paper is accompanied by six drawings, which have been reproduced in Plate 3.

Discussion.

Sir BENJAMIN BAKER, K.C.M.G., President, said the treatment of silver, copper or tin ore did not go on in Westminster, and the question might only remotely affect the majority of the members present, but there were others who were keenly interested in the subject, and the meeting, as representative of the absent members, would, he was sure, join in passing a vote of thanks to the Authors for their very valuable Papers. Sir Benjamin Baker.

Mr. JOHN H. CLEMES observed that the lixiviation process had suffered a considerable change since its introduction, partly on account of the fall in the price of silver, and partly from another cause which he would mention. At first it encroached on the amalgamation process; but, of late years, the smelting processes had encroached on both the amalgamation and the lixiviation methods of treatment. It was first necessary to increase the output of the roasting furnaces. If that could be done, as had been the case with copper-smelting, it would, with other things, go far to render the process still more useful. Again, when ores were roasted there was a considerable percentage of loss, much of which was not recovered. The flues were made small, the current of gases moved with great rapidity, and the fume had little opportunity to settle. He had been struck with a plan mentioned by Mr. Cowper in a discussion at the Institution in 1893 on smelting processes,[1] and especially with the enormous amount of fume obtained by its means. The principle aimed at was greatly to increase the area of certain of the flues, that the smoke might move slowly, and that the fume might have a chance to settle. That was not done by making the flues at any one point very large, but by putting a number of flues together. No water was used; that was an important point, because the mud or sludge resulting from wetting the fume would be difficult to deal with. For the purpose of making the working of the process more economical, the two objects to be sought were to improve the existing reverberatory furnace by increasing its capacity, and to improve the means by which the material now volatilized and lost could be recovered. Mr. Clemes.

---

[1] Minutes of Proceedings Inst. C.E., vol. cxii. p. 176.

D. C. Le Neve Foster.

D. C. LE NEVE FOSTER asked the Author of the second Paper whether *Figs. 1* and *4*, pp. 129 and 133, showed sections through the lode. If so, they were certainly somewhat peculiar. It was curious that the wide lode, *Fig. 1*, should so suddenly run out to what appeared to be a narrow fissure, and end in almost a straight horizontal line. It appeared much more likely that, just as happened at Rio Tinto, the upper part of the lode should continue of equal width although in an altered state. Again, a mass of decomposed ore of equal width coming to the surface might have been expected, rather than the lode ending off horizontally in a straight line, *Figs. 4*. The term "pillar and stall working," which rather applied to bed mining, was apt to engender a certain amount of confusion. He understood the Author to say that the lode was divided into floors 33 feet thick, and that a network of galleries was driven 16 feet high. The process might perhaps be better described by saying that the lode was divided into horizontal slices about 16 feet in thickness, and that the alternate slices were worked away by a network of galleries at right angles to one another. Between each network of galleries a solid floor of ore was left, about equal to the height of the galleries. He thought the other method of mining was incorrectly described as an adaptation of the "long wall" system. The lode was stated to be divided longitudinally at equal distances by diaphragms or walls, but it appeared to be really divided crosswise by those diaphragms or walls. He should be glad to know why it was necessary to adopt that method. Was it not possible to work away the thick lode, or wide vein, by the ordinary filling-up method without making the preliminary cross-cuts, as he should prefer to call them? There was no doubt some reason for it; but it was not stated in the Paper. He thought the method involved the necessity of building a great many more dry walls than would be required if the wide lode were worked away by the ordinary filling-up system. As to a name for the method of working, he thought the process would be better understood if it were called, not an adaptation of the long wall method, but a process of stoping away cross slices of the lode by the overhand system, with complete filling up of the cavities left by the excavation of the ore. In reference to sampling, the Author had said, "A system has been instituted which is equivalent to mechanical sampling; each wagon at the pit-mouth, as well as on the tipping-ground, yields its quota," but he did not say how it yielded its quota. He presumed that from each wagon, as it left the tipping-floor, a sample was taken.

Prof. W. C. ROBERTS-AUSTEN thought the Proceedings of the Institution were rapidly becoming the mines of metallurgical information, for which metallurgists were extremely thankful. The processes described in the first Paper showed how enormously the application of the wet processes had grown in comparatively recent years. The 60-ton vats used in the extraction of silver from its ores in Mexico might be compared with the 500-ton vats in the cyanide process for extracting gold as carried out in Africa. He agreed with the Author that exceedingly accurate results might be obtained by hand-worked as compared with more modern mechanical furnaces, and where labour was so cheap it could hardly be expected that complicated mechanical furnaces would be introduced. He also agreed in the statement (confirming a view he had long entertained) that in processes where cupriferous ores were present in silver treatment, the necessity for employing the Russell process was almost done away with. It was exceedingly interesting to have a recent account of the wet process of extracting copper, but it only showed what excellent results might be obtained by what seemed at first sight to be a cumbersome and barbarous process. It appeared that the introduction of the water-tank, referred to in the third Paper, below the furnace to catch the liquid tin was an excellent and novel feature. He should have been glad if the Authors of this Paper had given other details as to the method of treating slags which were rejected by the Cornish smelters. Prof. Roberts-Austen.

Mr. B. KITTO remarked that the processes described in the first and second Papers, appeared to be successful only when carefully carried out, the products in each case in their different stages being analysed and closely watched. With regard to the third Paper, he thought, as Prof. Roberts-Austen had said, the tank under the furnace was quite new, but he questioned whether it was really necessary. He was under the impression that the amount of tin which got into the ground under the furnaces in the Cornish smelting-houses was very small. It had been stated by the Authors that in Cornwall the slags were sometimes very rich, and one case was mentioned in which slag used as road metal was found on analysis to contain 15 per cent. of tin. He had seen slags from Cornwall containing that amount, but at present it was difficult to find slags so rich. He saw no mention in the Paper of the amount of tin yielded by the analysis of the slags. He had good authority for believing that the primitive method of smelting by the Chinese, although adopted on a small scale, was very effective. He questioned whether the Mr. Kitto.

Mr. Kitto. smelting as carried on in the reverberatory furnaces, taking the different scales of operation into account, was really more economical than the old Chinese method.

Mr. Barnett. Mr. A. K. Barnett, referring to the last Paper, could see no great distinction between the Cornish method of buying and handling the ore and that adopted at Singapore. In the latter case the cyanide method was adopted for the assays, whereas in Cornwall the tin was assayed by smelting a quantity of the ore with culm, which was similar to what was done on a large scale in the furnace; but cyanide was used also as a further guide. As to the preparation of the ore, the Authors wisely said that a smelter should throw as much of that duty as possible on the miner. In Cornwall the ore was, with few exceptions, bought in the state in which it was to be smelted. Occasionally parcels of ore were brought to the furnaces which might require a little washing, but there were not the appliances for what in Cornwall went under the general term of dressing. It should be remembered that the Cornish miner had to deal with a very different class of material from that of Singapore and the Malay Peninsula. Most of the tin obtained there was of a kind which had been worked in Cornwall hundreds of years ago. Deep mining had not been resorted to, and the vast amount of impurities had not been encountered. The average yield of Cornish stone did not exceed 2 per cent., so that 98 per cent. had to be separated before it was brought to the smelter. As to the method of mixing and storing the charges, a great deal must depend on the surrounding circumstances. What was absolutely essential in Singapore might not be necessary in Cornwall. That would apply especially to piece-work. Where a large number of men were employed, piece-work was generally recognised as an economical method of working. In Cornwall the total number of men employed in the largest smelting works was only sixteen night and day, so that no great economy could be effected in labour. The men were not paid by the hour, but in many cases belonged to families that had worked for generations, and took as much interest in what they were doing as the proprietors or managers themselves. There were two shifts of twelve hours, from six in the morning till six at night, and from six at night till six in the morning. During the night, when four furnaces were at work, with two charges in each, the labour of wheeling the charges to the floors, tapping the furnaces, ladling out the metal, removing the slags and everything else, rested on five men. There was one man at each furnace, and another man, locally known as a "tender,"

waiting on the four. As to the water-vault, he had intended to bring from Cornwall, as a practical illustration, a tin dropping, which would have shown that a water-vault was not an absolute necessity, as it might be at Singapore. It was stated in the Paper that a temperature of 260° C., above the melting-point of tin, was found at a depth of 3 feet or 4 feet below the vault of the furnace. In Cornwall, any leakage which came from the bottom of the furnace, instead of sinking into the ground below, really formed a stalagmite by a succession of drops built up. At a temperature of 260° C. it would not be possible to get a stalagmite because the tin would melt and percolate through the ground. In regard to the construction of the furnace, he was reminded of what Dr. Percy had formerly said in relation to a chemical analysis going into seven places of decimals, which he called "an affectation of accuracy." He was inclined to say the same in reference to the details mentioned in the Paper about the squaring of the brick, the use of the screw-jack, and the like. In Cornwall no skilled labourers were employed. The furnaceman built his own furnace, and having examined the bricks to see that they were sound and square, built them into the bed without a jack or anything of the kind. He could rebuild the furnace-bed in two days. In a case of entire rebuilding, including all the interior lining, the bed, the roof, and the fireplace, the men would let the furnace out on Saturday night, get the water poured in during Saturday and Sunday, and by the following Friday night, or Saturday morning at the latest, everything would be ready and the fire lit for the next smelting. To turn out a furnace and rebuild it in one week was, he thought, fairly expeditious work. It was stated in the Paper that the slag taken off at the first operation gave a yield of 30 per cent. or 40 per cent. He had not seen any slag containing so high a percentage. It was stated that on microscopic examination of the ore brown patches were found partly fused. If in the first smelting operation the reduction of the oxide was not complete there was certainly great risk that the unreduced tin-oxide would be coated over by slag, leading to extreme difficulty in reduction at a later stage. He did not see the advantage of large 4-ton furnaces. He did not object to large furnaces, but he should be glad to know why they were so large as the Authors had described. In Cornwall 2-ton furnaces were adopted, which he considered a reasonable size. With the 4-ton furnaces he understood that only three charges could be drawn in twenty-four hours, and eight-hour shifts were therefore necessary. The result would be 12 tons in Mr. Barnett

Mr. Barnett. twenty-four hours. With 2-ton furnaces working four charges there would be 8 tons in twenty-four hours. Larger furnaces would entail different arrangements with regard to the men. Each set of men smelted two charges of ore. He could not see that any great economy in fuel or otherwise would result from changing. With regard to the refining and boiling operation, in Cornwall all the metal was run out into a large kettle by liquation. Green wood was put in, and the gases escaping from it kept up a constant ebullition. That exposed and oxidised the impurities associated with the tin. The top was then skimmed off, and the skimmings were somewhat analogous to the ordinary hardhead. The tin was subjected to the mechanical tests referred to by the Authors, and if satisfactory was ready for the market. He could not agree with the Authors' objection to the Cornish rough mechanical process to determine the commercial quality of the tin, or with their preference for rolling. He knew that the best quality would give a wire edge on rolling, and an inferior quality would give a broken serried edge. Still, his experience differed from that of the Authors in regard to the question of copper. It was often found in Cornwall that traces of copper did not interfere with solder manufacture. He had never had a fair coppery tin returned as objectionable from the solder maker; it made a high-class solder tin. Arsenic was much objected to and should be got rid of. With regard to the use of the Siemens regenerator furnace, he saw the difficulty attaching to it in consequence of its blocking the air-chambers and other things of that kind. He still believed in gas-fired furnaces, and should be glad to see them tried at Singapore, where the fuel was expensive and the plant was much larger; he should advise the use of the Wilson gas-producer, to see if a gas-fire could not be obtained apart from the ordinary furnace. The percentage contained by Cornish slag had been mentioned by the Authors, but not the percentage in the works they were dealing with. As to slag being thrown away as road metal which contained 15 per cent., Cornish smelters had not so disposed of their refuse slags for fifteen or twenty years. They found a ready market for them in Wales. One reason why they did not smelt their own refuse slags, was that they had to buy their fuel; and another was that they would have to enter into competition with the very people who bought the slags for the next product which was desirable—lead refuse of some kind. They had an advantage because they could buy the various refuses from the Welsh tin-platers. Having that advantage they were able to work the Cornish

slag more economically than it could be worked in Cornwall. He remembered an axiom of Dr. Percy, "The end of all metallurgical operations is the balance-sheet." After referring to the Chinese method, the Authors stated: "The enactment of these (regulations), or any other cause for an increase in the price of charcoal, would undoubtedly render the Chinese tin-smelters unable to compete against the more refined and economical method of smelting with coal and anthracite in reverberatory furnaces." He would call attention specially to the words "more refined and economical method." Yet in a later paragraph the Authors referred to the Chinese smelting their ores on an entirely different principle, adding: "From these considerations, it may be supposed that an entirely new method of smelting cassiterite could be devised; and the future may yet show that the Chinese are working on a more economical principle than Europeans." Certainly those two paragraphs appeared contradictory. Perhaps the Authors meant that while the Chinese principle was right, their practice was wrong, and that if the Chinese principle could be put into better practice, an improvement might be effected. It was further stated by the Authors that the tin industry in Cornwall seemed to be suffering from the lowness of the price of the metal and the increased production in the Straits Settlements. There was one point which they had overlooked, and it was a most important factor. In Cornwall tin was sold for £60 per ton, and for that labour and everything had to be provided. The tin was exported from the Straits to England at £60 per ton, and sixty golden sovereigns (or at least the portion necessary for their work, minus profit) could be changed into Mexican dollars equal to about £100. He thoroughly agreed with the Authors in urging strongly "how vast is the room for improvements in tin-smelting, perhaps the oldest, and certainly one of the most backward, of English industries." Although tin containing a minute quantity of arsenic would "cry," it would require a very large amount of impurity to effect such a result. Mr. Barnett.

Mr. B. Blount observed that an interesting statement had been made in the first Paper tending to show how entirely tradition might rule, even in enterprises which depended primarily upon novel principles. Calcium hyposulphite, and similarly calcium sulphide, had been used almost exclusively in the treatment of silver ore, apparently for no reason except that lime was on the spot. On investigating the question of cost, it was found that the cost of sodium salts was not much greater and presented certain advantages. Seeing that crystallized sodium hyposulphite contained Mr. Blount.

Mr. Blount. a large percentage of water, a certain advantage would be gained (in saving of freight) by sending the salt out dry, if that was feasible. It was stated by the Author that, "The calcium sulphide employed for precipitating the silver always contains some calcium hyposulphite, which partly accounts for the increase in the volume of the stock of solvent." With that view he was in accord, but he did not think the reason for it had been properly expounded. It was further stated, "Flowers of sulphur and caustic lime are boiled together with such an addition of water that the resulting solution of calcium polysulphide marks 8° to 10° Baumé." But besides calcium polysulphide, calcium hyposulphite would also necessarily result. The one could not be obtained without the other. There was a certain amount of oxygen from the lime to be disposed of, and it appeared in the form of hyposulphite. With reference to the third Paper, he was particularly impressed with the Authors' statement as to the extreme liquidity of molten tin; and the device which he had adopted, and which had been extolled by Prof. Roberts-Austen, was certainly a reasonable one. He dissented from the view of Mr. Barnett, who apparently upheld the Cornish practice because it had been carried on to the third and fourth generation. He thought it should have a more valid basis than that. The chemical change involved in the reduction of tin ore was stated to be represented by the equation $Sn\,O_2 + 2\,C = 2\,CO + Sn$, being regarded as endothermic. It seemed uncertain that the reaction was endothermic at the temperature prevailing in the furnace. It might also be contended that the main reaction took place with the oxidation of CO to CO_2, in which case the reaction would be exothermic. With regard to refined tin, many interesting points had been set forth. It was said that buyers were accustomed to choose their tin by methods which, with the most lenient views, must be denominated crude. An analysis would tell all that was wanted. It was stated that tin with as little as 1 part in 10,000 of arsenic would have a crystalline fracture. He could corroborate the statement in the case of antimony, for which a very small amount of tin had a profound effect. Alluding to the Chinese smelting of tin, it was stated in the Paper that the men worked in a very moist atmosphere. From this it was deduced that they used water-gas, although they did not know it; certainly, if that was the case, the atmosphere must be abnormally moist.

Mr. Clemes. Mr. Clemes, in reply, believed the presence of hyposulphite in the calcium-sulphide was distinctly indicated in the Paper. It was a necessary result of the manufacture. He quite agreed,

however, with Mr. Blount's statement as to the probable superiority of sodium salts, which he thought was borne out in the Paper. He had attributed a good deal of importance to the question of temperature in roasting, but the necessity of carrying out the roasting in a highly oxidizing atmosphere might also be emphasized. Trouble had sometimes arisen in the working of one or two types of automatic furnaces from the lack of means to fulfil this condition; sufficient air could not be introduced at the right time or in the right place, and, consequently, the reactions to which he had referred occurred afterwards. Cases had been observed in which pulp roasted under this unfavourable condition had, immediately after being dropped from the furnace, yielded satisfactory results to the usual tests, 90 per cent. or more of its contained silver being extracted by a hyposulphite solution. But after being sprinkled, allowed to lie on the cooling-floor, and leached with water, it was found that the amount of silver soluble in "hypo" had greatly decreased, a number of tests showing 80 per cent. and upwards, and a few as little as 70 per cent. of the contained silver to be extractable by such solutions. Mr. Clemes.

Mr. COURTNEY stated that a perfectly correct representation of the sections of the lodes was given by *Figs. 1* and *4*; there was no mass of decomposed ore rising to the surface, but only as indicated in *Fig. 1*, and one of the interesting and peculiar features of the lodes was that both in length and width they were remarkably level on the top, there being in some cases a slight undulation on the surface. *Fig. 4* showed by no means an unusual form for the lodes to take, but generally the larger and wider masses were of such great and unworkable depth that it was not known exactly what form they assumed at the lower levels. In one case a diamond bore had passed through one of the lodes at 590 feet depth from the surface, or 240 feet below the lowest possible workings, whilst at the 350 feet depth the lode had not decreased in width, and from the general indications there was no reason to believe that in this case there was any diminution of width at the lowest point touched by the bore. The only justification for the use of the term long wall was that the system employed enabled the whole mass of the ore to be removed, and to carry out this method the lode was cross-cut at equal distances, and at right angles to its major axis, the space being filled with dry-stone walling and waste. This method could only be successfully employed where the lode was of moderate width, as in the case given, and the walling became necessary to resist the enormous pressure and consequent creep of the decomposed foot- and hanging-walls, which filling alone would not Mr. Courtney.

Mr. Courtney. prevent. The lode was attacked in several places at the same time, and if carefully arranged any intervening slices of ore that were designedly left between the diaphragms could be removed, and waste only inserted as the ore was extracted. The samples had been taken by a sampler, who was supplied with a shovel and hammer combined, of about 20 inches in length, and was used as a gauge. The shovel was placed against the end of the wagon and the hammer directed towards the centre; whatever piece of mineral it touched was taken, thereby obviating any possibility of choice. These samples were placed in a box, and at the end of the day's work sent to the mill for the necessary mixing and reduction in bulk. The variations in the percentage of copper between the samples taken at the pit-mouth and local treatment ground or the port of embarkation under this system were very trifling.

Mr. McKillop. Mr. McKillop observed that there was practically no difference between Cornish so-called "glass" slag and Pulo Brani "first" or "rich" slag. The one might be richer or poorer in tin than the other, but as metallurgical products they differed only in quality, not in nature. The treatment which he would have adopted to extract the metal from them would be that given in the Paper, with a modification in the amount of iron added; obviously, a lower percentage of tin required a smaller quantity of iron to displace it. The quantity of tin which penetrated into the ground under and round a furnace was very large. He believed that on removing a furnace in Cornish smelting-houses the accumulations discovered were considerable, and were regarded as a material assistance towards the cost of renewals. It was noteworthy that ore was bought in Cornwall on the anthracite assay which could not yield as high a result as the cyanide assay. From this it followed that an examination of the books and accounts of a smelting-house would not necessarily reveal a deficiency of tin, when there were considerable accumulations below the furnaces, and the quantity obtained and sold might agree closely with the quantity estimated by the assays. When the tin was actually recovered on rebuilding, its value was so much "found money," and might be regarded as a source of loss to the miners, not as a loss recovered by the smelters. The stalagmitic formations referred to were common in all tin furnaces, but a change of wind or the closing-up of any air-hole in the vault would cause them all to disappear in an hour or two. In Australia the usual method of recovering the "tin droppings" or "candlesticks," as they were called, was to stop all the air-holes in the vault, when they melted and ran down to a small basin

laced conveniently for ladling from the outside. It was while Mr. McKillop. he tin was in this melted condition that it leaked away, and coninual though small increments made up in a few months a large quantity. Perhaps there was an average higher temperature under and round the Straits 4-ton furnace than under and round the Cornish 2-ton one, but this did not prove the non-existence of the evil in Cornwall. The average percentage of tin in rejected slags at Pulo Brani was given at p. 160 as 5 per cent. This was an average figure, the results of many months' assaying by Mr. Ellis. There was variation normally between 9 per cent. and 1½ per cent. It was not found economical to work below 5 per cent., and anything above that was admitted to be bad work. With cheaper coal and more reliable labour there was no reason why 3 per cent. should not be the regular average, and it might be possible to work at an even lower figure, as was regularly done in German works. It was sufficient to admit that Straits ores were very largely "stream" ores. Still, "lode" ores were coming into the market, and would increase in the future. At the same time it must be remembered that stream ores were not all pure, or even approximately so. Many months' assay returns showed 70·3 per cent. as the average tin content. On the question of labour the Authors were of opinion that one establishment on the lines of Pulo Brani would smelt all the Cornish ores at less labour-cost per ton of metal than now obtained in Cornwall. Unfortunately this must remain a matter of opinion only; there was no comparison of a satisfactory nature possible. Fire-bricks reached Singapore after considerable knocking about in a steamer. In Cornwall they required much less handling in transit. He had known actual breakage to reach 23 per cent., and this would be an indication of the state of a shipment in the worst case. The average might be taken at 8 per cent. or 10 per cent. Chipping went *pari passu* with breakage, and hence the greater care that seemed to be required with bricks used for beds at Pulo Brani than in Cornwall. The 2-ton furnace was obsolete everywhere but in Cornwall, and even there it was rumoured that 3-ton furnaces were being introduced. At Pulo Brani the first ones built were of the 2-ton size, but increased capacity was found by trial to be accompanied with greater economy. The limit was reached when the furnace tools became too large for convenient handling. Any further change in size would have to be accompanied by change in principle. It was worthy of note that the gas furnace that was tried smelted a charge of 6 tons in a very satisfactory manner as far as working the charge was concerned. The air and other passages

Mr. McKillop. were not blocked as much as was the case in steel furnaces which the Authors had seen in the north of England, Scotland, and Belgium. The gas regenerative furnace had been successfully applied in spite of *a priori* apparent objections; the point to note was that the regenerator chambers must not be placed below the hearth for reasons which it was the main object of this Paper to emphasize. Straits tin had to stand a higher test than any other. The best of it was used by foil-makers on the continent of Europe, and for this purpose the usual bending test was valueless. It might also be pointed out that a large quantity of Straits tin went to Cornwall to be mixed with Cornish tin, after which it was resold as "English." This portion also required to be of good quality. Any one who had worked a furnace could not have failed to notice that the temperature rose with extreme rapidity at the conclusion of the action in any charge. This indicated that there was an absorption of heat during the reduction of $Sn\,O_2$ by carbon, but this was not the only possible explanation of the phenomenon. The Chinese method was a most interesting one, and would repay careful investigation. No one could possibly contend that the method was an economical one. The clouds of tin fume leaving the top of the furnace, the thick deposit of tin oxide which covered everything in the smelting-house, the price of the charcoal required, which was three or four times as dear as coal, the small production per man, all pointed to the wastefulness of the method. The principle of water-gas reduction, on the other hand, was capable of economical application, and would have to be made use of in the future.

Correspondence.

Mr. Bromly. Mr. A. H. Bromly, of Nankan, Upper Burmah, asked, with regard to the first Paper, for further information as to the output, or preferably the duty per effective HP. per hour, of the 1,000-lb. stamps when used for dry-crushing. The duty of the stamps when working with a coarse screen followed by sieving and return of over-tails to the mortar-boxes would also be interesting. Such data would enable a valuable comparison to be made with stamps when crushing wet. Under the latter conditions the duty varied accordingly as the stamp was run with a view to large crushing capacity, or mainly as an amalgamating apparatus. A wet-stamping 800-lb. mill, with 90 drops per minute, a lift of 8 inches, and an average depth of discharge of 8 inches, had a duty of about

1·18 cwt. per effective HP. per hour when crushing hard quartz through a sieve of 40 meshes to the lineal inch. This mill was run for amalgamation rather than large output. Upon the Rand, where the conditions to be fulfilled almost exactly corresponded with those prevailing in the lixiviation process, the duty of wet-crushing stamps was between 2·5 cwt. and 3·0 cwt. per effective HP. per hour. The reduction of duty due to crushing dry had been stated to be as much as 75 per cent., and it would be interesting if the Author could supply figures bearing upon this point, especially as it was generally assumed that in this connection a well-designed roll-plant was a superior and more economical method of reduction. Rock-breakers being common to both systems might be neglected. Referring to the question of fine dust or "slimes" as affecting lixiviation, if the Author would furnish figures as to the condition of the products from mills running under the two systems they would be extremely valuable as establishing a record of a good leachable product upon such ores. It was stated that the rate of filtration was nearly doubled in one case by coarse-crushing and after-sieving. He found the 800-lb. mill above mentioned to give a pulp with between 58 per cent. and 64 per cent. by weight through a 120-mesh sieve and when crushing through one of 40-mesh, the ore carrying about 5 per cent. of sulphides. His experience with rolls crushing hard quartz through 30-mesh sieves showed that between 15 per cent. and 35 per cent. passed 120-mesh, the percentage varying according as the plant was being crowded, or otherwise. Gruson ball mills crushing quartz through 70-mesh gave 5 per cent. through 120-mesh. It was not stated in the Paper whether the fine dust exhausted from the mortars required separate treatment, or was merely mixed with the remainder of the pulp. He would be glad also to know what was the matrix generally of the ores under consideration, this factor being necessarily most important in the construction of a reduction-plant. Mr. Bromly.

Mr. Bennett H. Brough pointed out that, in his description of the geology of the Tharsis district, Mr. Courtney had omitted to refer to the controversy that had long existed as to the true nature of the deposits. As far back as 1876 Mr. F. Roemer[1] had enunciated the view that they were of sedimentary origin and strictly conformable to the surrounding beds of slate. On the other hand, Mr. J. Gonzalo y Tarin,[2] in 1887, had announced his adherence to Mr. Brough.

[1] "Zeitschrift der Deutschen geologischen Gesellschaft," 1876.

[2] "Descripción física, geológica y minera de la provincia de Huelva" (Memorias dela comisión del mapa geológico de España). 1887–1888.

Mr. Brough. the view that the deposits were veins or lodes formed by subsequent infiltration of ore between the surrounding beds, and that view was shared by Mr. de Launay[1] in 1889. The matter had, however, been definitely settled by Professor F. Klockmann,[2] of Clausthal, who, in 1894, brought forward a series of arguments proving the bedded nature of the deposits. The age of the surrounding rocks, which the Author stated to be either Silurian or Devonian, was also a matter of controversy. They were considered by Mr. Roemer to be of Lower Carboniferous age, but the results of an examination of the fossils obtained by Mr. J. H. Collins[3] in 1885 clearly proved them to be of the Upper Devonian period.

Mr. Dawson. Mr. BERNARD DAWSON thought it probable that a regenerative gas furnace might be designed for tin smelting, in which it would be impossible for metallic tin to reach the regenerator chambers, and in which the cost of repairs and renewals, and the time lost while they were being carried out, might be reduced to a minimum. Furnaces of this character were in use for smelting nickel and other ores, and had effected great economy both in the price and in the weight of the fuel formerly used in the reverberatory furnaces they had successfully replaced. Without some knowledge of the design and construction of the gas furnaces mentioned by Messrs. McKillop and Ellis, it was impossible to determine whether they were fitted for their purpose; but that furnaces could be built to do this work successfully, and with some saving in the labour of charging and manipulation of the ores and the finished product, was without doubt.

Prof. Louis. Professor HENRY LOUIS had, during a three years' residence at Singapore, had frequent opportunities, by the courtesy of Mr. McKillop, of studying his process of tin-smelting. He had no doubt that the mixed carbon and iron-reduction method was decidedly superior to what might be termed the Cornish or simple carbon-reduction method. Cleaner slags were obtained by the former, and the consumption of fuel was necessarily less. As Messrs. McKillop and Ellis had pointed out, the direct carbon-reduction was a strongly endothermic reaction, whilst the iron reduction was only slightly endo-, if not actually exo-thermic. Now in the Pulo Brani process, only 80 per cent. of the tin was extracted by the former method, leaving 20 per cent. to be dealt with by the cheaper method as regarded fuel.

---

[1] "Mémoire sur l'industrie du cuivre dans la region d'Huelva," Annales des Mines, vol. xvi. 1889, p. 427.

[2] Sitzungsberichte der königlich preussischen Akademie der Wissenschaften zu Berlin, vol. xlvi. p. 1173.

[3] Quarterly Journal of the Geological Society, vol. xli. p. 245.

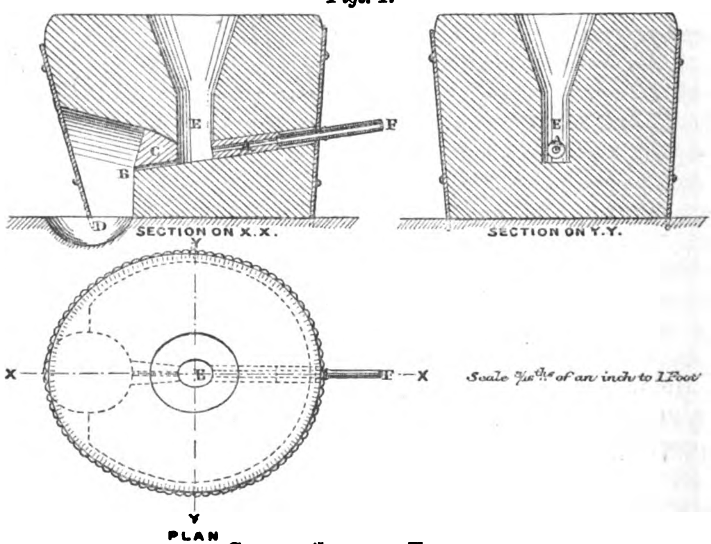
The first was the great point to be looked to; in smelting a metal worth £60 or more per ton, consumption of scrap iron or even of fuel was a small matter compared to clean slags. He noticed the tin contents of the slags were stated in the Paper at about 5 per cent., but his impression was that a good deal of slag was produced that was much cleaner than that, and that volatilization and soakage into the ground accounted for a good deal of the loss; in volatilization he included ore mechanically carried off by the furnace as well as metal actually vaporised. The loss, however, under these heads was not referred to in the Paper. Prof. Louis.

With the most of the Authors' views he was in entire agreement; indeed, he thought the process described was a distinct step in advance in the metallurgy of tin. With regard to future improvements, it might, however, be possible to suggest a few that the Authors had not referred to, especially with the object of saving fuel, which often meant also saving of time. Thus he should like to know whether there was any good reason why, in a properly arranged plant, the rich slag should not be run direct into a specially designed slag-furnace. He would point out the immense improvements that had been recently introduced into the metallurgy of copper in America, by treating direct in the molten state products that used to be at one time granulated and subsequently remelted. The time and fuel that might be saved by such direct treatment of molten slag were obviously considerable.

He did not entirely agree with the Authors' views on the Chinese method of tin-smelting, which he had had repeated opportunities of studying. In the first place, the ore treated by Chinamen was very pure; almost the only impurities in it consisted of ilmenite and magnetite. Wolfram was conspicuous by its absence, and this, together with the various forms of pyrites, was to be found principally in the lode tin of Pahang (which was not worked by the Chinese), and in certain districts of Perak. As far as he had seen, the tin from Selangor and Hulu Pahang was extremely pure. The Chinese used two forms of furnace, a draught-furnace and a blast-furnace; their construction was similar, consisting of a short cylindrical or slightly conical stack made of clay, kept in place by bamboo poles and hoops; the interior consisted of a crucible between 9 inches and 12 inches in diameter, cylindrical at the bottom for more than a foot, with a conical stack 2 feet to 2 feet 6 inches high, opening outwards to a diameter of about 2 feet or more at the top. There was a small tap-hole in front, and an opening at the back that admitted a clay

Prof. Louis. tuyere about 1½ inch in inside diameter, or, in the other type of furnace, admitted a couple of short clay pipes about 3 inches in diameter. The draught-furnace was preferred, but could only be used with first-rate charcoal. The furnace, *Figs. 1*, was a mass of clay with bamboo stakes driven into the ground around it, and bamboo hoops to hold it together. The actual furnace, or crucible, was at E; A was a moulded cylindrical clay tuyere between 5 inches and 6 inches in diameter, 2½ inches bore, and about 22 inches long. The bamboo blast-pipe was shown at F, which conducted the blast from what was practically a double-acting blowing cylinder made of a hollow tree-trunk, 12½ inches in diameter and 10 feet long,

Figs. 1.



CHINESE SMELTING-FURNACE.

with a wooden piston packed with leaves or feathers. One man mostly did the blowing, more rarely two. The blast was irregular and intermittent, and the average speed probably did not exceed ten strokes per minute. The front of the hearth was arched, and the crucible itself was closed in front, when at work, by a lump of clay, C, through which a small tap-hole, B, about ¾ inch in diameter, was kept open by means of a stick, or at times an iron rod. The tin trickled into a hole, D, in the ground lined with clay—the Chinese equivalent of the "flote." The molten tin was kept covered with burning charcoal, and from time to time was ladled out and cast into pigs by means of a sand mould, a wooden

block being used as a pattern. Each pig weighed 60 kati (80 lbs.). The exact consumption of fuel was difficult to ascertain, and varied with the quality of the charcoal within wide limits. He had been informed by some Chinamen that they used as little as 30 per cent., others as much as 100 per cent. of the weight of the ore. Thus about 60 per cent. of tin was obtained from ore that probably contained 68 per cent. or 69 per cent., together with a small amount of very rich slag. This slag was pounded under a rough tilt hammer, washed to extract the prills of metal, and then smelted in small furnaces about 2 feet 6 inches or 3 feet high, these poundings and smeltings being repeated between four and six times before the slag was thrown away as worthless. Now, in watching an operation in one of these furnaces, the top would be found to be comparatively cold; the tap-hole was so cold that even the fusible iron and tin silicate were pasty, and would not run freely, all the heat being in a small reduction zone about the tuyeres. He could not, therefore, agree with the Authors' view that a water-gas reduction took place here. There were three other methods of reduction that might act, and that were more probable than the water-gas hypothesis:—(1) Direct reduction of the tin oxide by carbon or perhaps by carbonic-oxide in the region of the tuyeres. (2) There was always some magnetite with the ore, which would be reduced to metallic iron in the furnace just above the tuyeres, and this would in its turn reduce the silicate of tin. (3) It was most probable that the nitrogen of the atmosphere, in the presence of the alkaline carbonates in charcoal-ash, would combine with some carbon to form cyanide of potassium, which, volatilised by the heat of the tuyere zone, would condense somewhat higher up and would reduce the ore at a very low temperature. It was well known that alkaline cyanides were formed under perfectly analogous circumstances in the blast-furnace, and the readiness with which such cyanides reduced oxide of tin was equally well known. He had no doubt that all three of these reactions came into play in the Chinese method of tin-smelting, and had great doubts whether water-gas played any part at all in the reaction. At the same time he might add that it seemed quite possible that reduction in a blast-furnace —perhaps with the injection of alkaline-cyanide to help the reaction—might ultimately prove a better method of tin-smelting than that of treatment in reverberatories. Prof. Louis.

Mr. Ernest A. Smith observed that it had been stated by Messrs. McKillop and Ellis that "any ore containing arsenic or sulphur is thoroughly roasted at least once. The furnace is of the 'blind Mr. Smith.

N 2

Mr. Smith. roaster' type, the ore being in a muffle, out of direct contact with the fire." Although this form of furnace, from its gentle and regular heat, no doubt possessed decided advantages in many cases, yet its high cost of construction, and greater consumption of fuel, were somewhat adverse to its employment. It would be of interest, therefore, to know what special advantages were derived from the use of the muffle furnace, for roasting the ore under consideration, in place of the Oxland and Hocking calciner, and other forms of roasting-furnaces in use in Cornwall for the treatment of tin ores. The fact that the "cyanide" method of assay was used exclusively for determining the value of the ore was also of interest, as in Cornwall preference was usually given to what was known as the "Cornish" method of assay, although both methods were sometimes employed. The "button" of tin obtained from ore assayed by the "cyanide" method was practically pure when the assay was carefully conducted, and more truly represented the percentage of tin present in the sample. Yet it was claimed for the "Cornish" method that the resulting tin "button" represented the quality of metal the smelter might expect to obtain in the smelting of the ore, as this method of assay was practically the "smelting operation" conducted on a very small scale, powdered culm being used to effect the reduction of the tin oxide. It would appear that the question of gaseous firing merited a more extended trial.

Mr. Clemes. Mr. Clemes, in reply to the Correspondence, stated that the duty of the 1,000-lb. stamp-mill was between 2,500 lbs. and 3,000 lbs. per stamp in twenty-four hours. The same mill, with wet crushing, would probably accomplish between 4,000 lbs. and 5,000 lbs. in twenty-four hours.

Mr. Courtney. Mr. Courtney observed, in reply, that the controversy as to the nature of the deposits had not been referred to, as it would seem to be never-ending. The latest information was undoubtedly given by Professor Klockmann, who, after a visit to the mines, had communicated his conclusions to the Berlin Academy of Science. They were, however, opposed by others who had recently investigated the subject, so that Mr. F. Roemer's enunciation of 1876 was recalled, with the contrary opinion formed by Señor Gonzalo y Tarin in 1887. He ventured the opinion that further investigation would tend to strengthen rather than otherwise the conclusions of Señor Gonzalo y Tarin.

Mr. McKillop. Mr. McKillop, in reply to the Correspondence, remarked that it had been considered unadvisable to enter into details on the subject of the structure of the gas-furnace built at Pulo Brani.

A furnace, however, could be built so that no metal could get into the chambers, and with experience the expenditure on repairs would be greatly reduced. The greater part of the expense at Pulo Brani was in connection with the producers, and by this time it was fair to assume that these were well enough understood to obviate any serious difficulty in adapting them to new conditions. The twelve months' experience at Pulo Brani convinced all concerned that the gas furnace was in principle entirely satisfactory; unfortunately the arrangement adopted in this particular case was really bad and it had to be condemned. It was undoubtedly true that some slags contained less than 5 per cent. of tin, but that amount was given as a real average. During the period in which the materials for the Paper had been collected, slags were obtained in which only mere traces of tin could be detected. But work of this high efficiency could not be expected regularly, especially with Javanese labour, and the Authors had no hesitation in expressing the opinion that an actual average of 5 per cent. would compare very favourably with the average in other works. Loss by volatilization appeared more serious than it really was. The flue was always closed during charging, and "tin fume," which rose from the surface of exposed metal, was not really a source of serious loss. In the first place, a watchful foreman could detect its formation at once and stop it by rabbling, and, in the second place, some experiments he had made, in conjunction with Mr. Ellis, showed clearly that an exposed surface of metal would apparently evolve large quantities of fume and still lose very slightly in weight. The question of running slags direct into secondary furnaces and treating them without allowing them to cool had been considered; it was thought to be perfectly feasible, but it demanded a very large scale of operations. The main cause of the backwardness of the metallurgy of tin was to be found in the smallness of the tin-works. A capable engineer in a large work would soon introduce these very obvious improvements. The remarks of Professor Louis were full of interest, and only emphasized the opinion expressed elsewhere that the metallurgical method by which by far the largest quantity of tin was produced was worthy of much more careful study than it had yet received. The muffle furnace had been adopted because it was simpler and less costly than a revolving calciner, for small quantities, and was much more easily controlled than an open-hearth roaster of the ordinary type. Mr. McKillop.

24 March, 1896.

SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the Chair.

(*Paper No. 2963.*)

"The Thermal Efficiency of Steam-Engines."

By HENRY RIALL SANKEY, Capt. R.E. (ret.), M. Inst. C.E.

STEAM-engine economy has, during the last fourteen years, formed the subject of several Papers read before the Institution, and a considerable portion of them, and of the discussions which followed, have had reference to the standard with which the experimental results were compared. It is remarkable that, notwithstanding this repeated discussion, there cannot yet be said to be agreement amongst engineers as to the proper standard to be employed; and, in view of the inconvenience of such a state of things, the Author feels that little apology is needed for again bringing the question forward, in the hope of preparing the way for the adoption of some definite standard.

As to whether, in the first place, the absolute thermal efficiency of the actual engine should be used, or a comparison be made with an ideal engine, the Author considers that both efficiencies are required to give a clear view of the thermal performance of an engine, and that even erroneous conclusions may result if either be not taken into account.

The absolute thermal efficiency is defined as the ratio of the portion of the heat supplied which is converted into work, to the total heat supplied, and this efficiency must, for physical reasons, be very small. It is required for the following purposes:—

(1) To obtain the work-return of any particular engine without reference to others.

(2) To compare the conversion of heat into work obtained by various kinds of heat-engines, whether using saturated steam, superheated steam, gas, oil, or air, &c.

(3) To compare the conversion of heat into work obtained by

the same kind of heat-engine or even the same engine when working with different temperature ranges.

The standard efficiency can be defined as the ratio between the heat converted into work by the actual engine and that which an ideal standard engine, working under the same conditions, could convert into work, and varies between 50 per cent. and 80 per cent.; but there is no physical reason why it should not reach 100 per cent., although there are practical reasons to prevent a much greater efficiency than 80 per cent. being obtained. The standard efficiency indicates how nearly an actual engine has approached to what is physically possible under the conditions of working.

It will be observed that the absolute thermal efficiency and the standard thermal efficiency give information of different kinds, and moreover it frequently happens that engines that have a high absolute thermal efficiency have a low standard thermal efficiency. Thus a condensing steam-engine working with an admission pressure of 180 lbs. per square inch absolute, may have an absolute efficiency of about 17 per cent., whereas a non-condensing engine, working with the same admission pressure, cannot be expected to have a greater absolute efficiency than about 12 per cent. But the standard thermal efficiencies would be about 60 per cent. and 80 per cent. respectively; in other words, the condensing-engine, which of course gives the best absolute return, is nevertheless not doing so well (in proportion to its opportunities) as the non-condensing-engine.[1]

---

[1] The following two extracts illustrate this point:—

"He did not think that the Author was justified in taking the efficiency in the way he had done. He thought he could show from the figures in the Paper that it led to a very decided fallacy. In Table I, 'simple series,' four expansions, 27·8 lbs. of water, the 'efficiency' was put down at 67·1 per cent. Working the same engine with less than two expansions, with 42·76 lbs. of water, the 'efficiency' was 81·08 per cent.; so that the more the water was wasted, the better was the 'efficiency,' so called, which was obviously an error." —Mr. Cowper's remarks on Mr. Willans' Paper, "Economy Trials of a Non-condensing Steam-Engine," Minutes of Proceedings Inst. C.E., vol. xciii. pp. 233–4.

"Mr. W. W. Beaumont and Mr. C. E. Cowper pointed out, during the discussion, that in many cases the comparison of water used with water theoretically required was misleading, the efficiency as given being higher in certain cases in which the feed-water was greater, and Mr. Mair and Mr. Cowper thought the efficiency should be based on a comparison of the heat supplied with the heat given up in useful work. He agreed with Mr. Cowper that this was the only way of taking the 'absolute efficiency,' but he might observe that this method of comparing the efficiency was quite as misleading as

STANDARD THERMAL EFFICIENCY.

Many views are held as to what should constitute the ideal engine required as a standard of comparison. It has been advanced,[1] that it is immaterial what ideal engine is adopted, so long as comparisons are universally made with it.[2] Undoubtedly, the adoption of any agreed standard would ensure the good result, that all figures of thermal efficiency would be directly comparable. But it is not less important that the standard should be so chosen that it may be readily seen how far the particular engine considered falls short of what is physically possible within the limits of temperature by which the engine is bound. To strictly fulfil this requirement the standard of comparison ought evidently to be the perfect steam-engine, that is, it ought to be the particular

---

a comparison of the feed-water; because it took no account of the limitations which the working conditions themselves imposed, whereby the temperatures at which heat was received and was rejected were unalterably fixed."—Mr. Willans' reply to Correspondence on Paper, "Economy Trials of a Non-condensing Steam-Engine," Minutes of Proceedings Inst. C.E., vol. xcvi. p. 231.

[1] Minutes of Proceedings Inst. C.E., vol. xciii. p. 229; also *ibid*, vol. xcvi. p. 239.

[2] The following extract from Mr. Willans' reply to the Correspondence on his Paper, "Economy Trials of a Non-Condensing Engine," shows that it is of practical importance to select a proper standard of comparison:—

"In the technical journals, a few months back, particulars of an engine-trial were given, and it was stated that a non-condensing engine, working with 150 lbs. boiler-pressure, gave 1 HP. hour per 14·12 lbs. of water evaporated. Now the heat supplied to the above weight of water to convert it into steam taking the feed temperature as that of the exhaust steam, was 14,330 units. The heat converted into work per HP. hour = 42·75 × 60 = 2,565 units, or an absolute efficiency of $\frac{2,565}{14,330}$, or 0·179. This was an excellent result, but still one which Prof. Perry would consider that of a spendthrift engine; at any rate, it would seem to leave much to be desired. Comparing it with the work due from the Carnot cycle, however, the efficiency would suddenly jump up to 96·2 per cent. of theoretical possibilities, taking the Carnot cycle between the same limits of temperature as unity—a result which no doubt satisfied the experimenter.

"If, however, the result was compared with the work due from an ideally perfect steam-engine, namely, with the work represented by the area of the best diagram possible, as given by the formula of Clausius, it would be found that the actual engine gave 103·4 per cent. of the work theoretically possible, or 3·4 per cent. more power than could possibly be obtained from that weight of steam expanded between the boiler and atmospheric pressures. This result would probably, had he realized it, have induced the experimenter to make another trial, after overhauling his indicators and water-weighing apparatus."

ideal steam-engine which converts into work the maximum percentage possible of the heat-units supplied to it, having regard to the varying temperature at which the heat is supplied to the feed-water, and to the admission- and exhaust-temperatures. It will, however, be seen later that for practical reasons, which are universal and permanent, a slight modification is desirable in connection with the point to which the expansion is carried.

The cycle of the perfect steam-engine has been described by Clausius, Rankine, Tait and other authorities,[1] and is well known to be, (1) feed raised from exhaust temperature to admission temperature; (2) evaporation at constant admission temperature producing dry saturated steam; (3) adiabatic expansion carried down to back pressure; and (4) rejection of heat at constant temperature corresponding to back pressure.

The perfect steam-engine as thus defined was the standard advocated and adopted by the late Mr. Willans in both his Papers on steam-engine economy;[2] it may be said he made this standard peculiarly his own, and when it was criticised by several speakers in the discussion[3] on the earlier Paper, Mr. Willans effectively[4] maintained his position in his reply.

Various ideal Engines proposed as Standards.

Reference will now be made to some of the standards of comparison that have been used by engineers.

Carnot Cycle.—A heat-engine working on the Carnot cycle is probably the most usually accepted standard of comparison. An engine working on this cycle receives all its heat at the higher temperature and rejects it all at the lower temperature. The perfect steam-engine above defined, however, receives a part of its heat at temperatures varying between the lower and the higher limit, namely, that portion of the heat required to raise the feed-water from the lower to the higher temperature, while the remainder of the heat (namely, the latent heat of evaporation) is put in at the higher temperature. The absolute thermal efficiency of the perfect steam-engine is therefore necessarily less than that of the Carnot cycle engine, as will be seen by com-

[1] Minutes of Proceedings Inst. C.E., vol. xciii. p. 132.
[2] *Ibid*, vol. xciii. p. 134, and vol. cxiv. p. 2.
[3] *Ibid*, vol. xciii. pp. 227–229, 249 and 256.
[4] *Ibid*, vol. xcvi. pp. 242–245.

paring the following expressions, or as exemplified by the $\theta\phi$ chart, *Fig. 2*:—

Absolute efficiency of Carnot cycle[1] $= \frac{\theta_a - \theta_e}{\theta_a}$;

" " of perfect steam-engine of Clausius—

$$= \frac{\left(\theta_a - \theta_e\right)\left(1 + \frac{L_a}{\theta_a}\right) - \theta_e \log_e \frac{\theta_a}{\theta_e}}{L_a + \theta_a - \theta_e},$$

where θ_a and θ_e are respectively the absolute admission- and exhaust-temperatures, and L_a is the latent heat at temperature θ_a.

Inasmuch then, as the absolute thermal efficiency of the perfect steam-engine is the maximum physically possible, the Carnot cycle is an ideal impossible of realization; and hence, notwithstanding its general acceptance, it cannot be said to be a suitable standard of comparison when dealing with the actual steam-engines as at present constructed or contemplated. It is, in fact, a purely scientific abstraction, incapable of practical application without a dynamical feed-heater. The following Table shows the absolute efficiencies of the Clausius perfect steam-engine and of the Carnot cycle engine between various limits of temperature:—

—	Non-Condensing.		Condensing.		
Admission-, or higher, temperature, t_a	270° F.	370° F.	270° F.	320° F.	370° F.
Exhaust-, or lower, temperature, t_e .	212° F.	212° F.	110° F.	110° F.	110° F.
Clausius perfect steam-engine . .	0·075	0·176	0·207	0·248	0·284
Carnot heat-engine	0·079	0·190	0·219	0·269	0·313

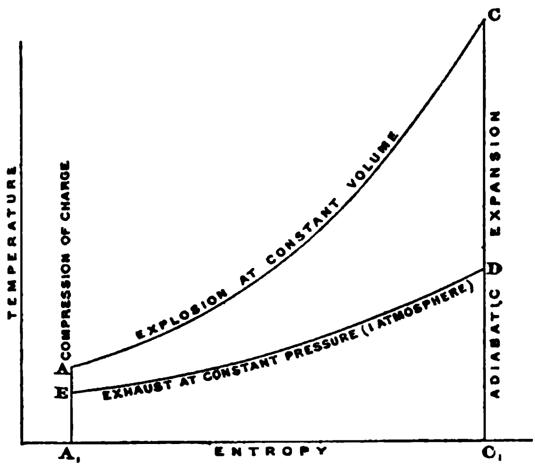
It will be seen from this Table that the difference between the Carnot cycle and the perfect steam-engine is considerable, especially with condensing-engines working with high-pressure steam. The difference is even more marked with engines using superheated steam, as will be shown later. The greatest difference, however, occurs in the case of gas-engines. For instance, A C D E, *Fig. 1*, is the $\theta\phi$ diagram of an ideal gas-engine, compressing the charge adiabatically, receiving all the heat produced by the explosion at constant volume, expanding aiabatically to atmospheric pressure, and exhausting at that pressure. The absolute thermal efficiency is $\frac{\text{area A C D E}}{\text{area } A_1 \text{ A C } C_1}$ = about 50 per cent., whereas the absolute thermal

[1] Minutes of Proceedings Inst. C.E., vol. xcix. p. 224.

efficiency of the Carnot cycle, working between the same limits, is about 90 per cent. It is well to realise this, not to raise false hopes as to the possibilities of gas-engines.

Jacketed Engine.—If the expansion-line, instead of being adiabatic, follows the saturation-line, the cycle is that of the ideal jacketed engine, in which the steam is kept saturated and dry during expansion by added heat. The absolute efficiency[1] of this cycle is less than that of the Clausius steam-engine, as will be shown later. Therefore it is unsuitable as a standard, because the standard thermal efficiency of an actual engine would be exaggerated if compared with it. Prof. Osborne Reynolds adopted

Fig. 1.



the saturation-line in his standard of comparison,[2] and further limited the expansion so that the release pressure in the standard was the same as in the actual engine.[3] This limitation in the expansion ought to prevent this cycle from being adopted as a standard for thermal efficiency, because one of the defects in actual engines which the standard is appointed to try, namely, incomplete expansion, is thereby altogether condoned; and no matter how defective in this respect the actual engine might be, the ideal engine is practically equally so. The objection is not, however, so much that the expansion is incomplete, as that it varies

[1] Minutes of Proceedings Inst. C.E., vol. xcix. pp. 226, 227.
[2] See under "Type Standard."
[3] Minutes of Proceedings, Inst. C.E., vol. xcix. p. 181.

with the release pressure in the actual engine. It is even the fact that the worse the actual engine is, in regard to limiting the expansion unduly, the more efficient it will appear, relatively to other engines, because in this respect the standard changes just as the actual engine does. Mr. Henry Davey, in his Paper[1] on "Steam-Engine Economy," practically adopted the same standard as Prof. Reynolds.

The comparison of the expansion-line of an actual engine with the saturation-line, although, as already shown, incorrect if the object is to find the thermal efficiency of the engine, is nevertheless of value. If the saturation-line is drawn on the indicator diagram (or on a combined diagram in the case of an engine in which the steam is in more than one cylinder), not through the actual point of cut-off, but through a later point, representing as saturated steam the whole of the feed admitted per stroke, then at any other point in the expansion the dryness fraction of the steam can be determined by a comparison of the actual expansion-line with the saturation-line.

An ideal engine having an expansion-line following the hyperbolic law ($p\,v$ = a constant) is also used for the purposes[2] of comparison. The absolute thermal efficiency of such an engine is, however, less than that of the Clausius steam-engine, working within the same temperature limits, and it is therefore unsuitable as a standard of comparison for thermal efficiency. The graphic comparison of the expansion-line of an actual engine with the curve $p\,v$ = constant, drawn through the point of cut-off is, however, of use in other respects, because the expansion-line of a large majority of actual engines, owing to initial condensation and re-evaporation, approximates to this curve, so that any material discrepancy will indicate something wrong with such engines. The fact that an expansion-line following the law $p\,v$ = constant is the indication of the defect of initial condensation,[3] is proved later, and for this reason alone it makes a most unsatisfactory standard.

Other standards of comparison have been suggested. For instance, Dr. A. B. Kennedy, F.R.S., mentioned three in his remarks[4] on Mr. Willans' Paper on "Economy Trials of a Non-Condensing Steam-Engine," but those referred to will suffice to show that there is a considerable disparity of views on the subject.

---

[1] Minutes of Proceedings Inst. C.E., vol. cxxii. p. 1.
[2] *Ibid*, vol. xciii. p. 249.
[3] *Ibid*, vol. xcvi. pp. 250, 251.
[4] *Ibid*, vol. xciii. pp. 227, 228.

The Author feels strongly, however, that the perfect steam-engine defined early in the Paper, but with the possible modification already referred to and discussed later, is the proper standard to use when it is desired to ascertain the degree of perfection reached by a particular engine, or when reporting the results of trials.

There is also another standard of comparison which is of use to the engine-designer, because it can be made to take account of the amount of clearance, compression, back-pressure, release, jacketing, etc., which are practically necessary in any particular type of engine under consideration. This standard might well be called the "Type Standard," and the difference in heat-units utilized by it and the standard steam-engine gives the absolutely unavoidable loss normal to the particular type of engine. Further, the difference in heat-units utilized by the actual engine and by the type standard shows the more or less avoidable loss, and may suggest improvement in the design of the engine. The comparison with this standard might be called the "Type Thermal Efficiency." The standard adopted by Professor Reynolds in his Paper "Triple-Expansion Engines and Engine Trials,"[1] is an example of a "Type Standard," and it was, no doubt, really in this connection that he used it, although this was only made clear in his reply, and some of his critics—notably Mr. Willans—were led to think that he intended it as a general standard applicable not only to the engine at Owens College, but to others.

Comparison of the various Standards by the $\theta \phi$ Chart.

The various ideal engines that have been considered can be compared[2] graphically by means of their $\theta \phi$ diagrams. The $\theta \phi$ chart, as usually drawn, refers to 1 lb. of H_2O.[3] The ideal engine should therefore consist of a cylinder fitted with a piston, and containing at all points of the stroke 1 lb. of H_2O behind the piston. If it is conceded that heat may be introduced into or abstracted from this cylinder in any desired manner, the transformation of the 1 lb. of H_2O can be so arranged that any indicator diagram (or $p\,v$ diagram) whatsoever can be reproduced.[4]

Thus, in the case of the perfect steam-engine of Clausius, the

---

[1] Minutes of Proceedings Inst. C.E., vol. xcix. p. 152.

[2] *Ibid*, vol. xcvi. p. 240.

[3] The chemical symbol H_2O is used, as the cylinder contains a mixture of steam and water varying in proportion at each point of the stroke.

[4] Minutes of Proceedings Institution of Mechanical Engineers, 1894, pp. 82–90; also *Engineering*, 3rd January, 1896 (translation of Prof. Boulvin's Paper).

cylinder contains at the starting-point 1 lb. of water at the lower temperature θ_c, and the state of the water is represented by the point A on the $\theta\phi$ chart, *Fig. 2*, and by the point *a* on the $p\,v$ diagram, *Fig. 3*. Heat being now introduced into the cylinder, the temperature of the water is raised to the higher limit of temperature θ_a. During this stage the state point of the water moves

Fig. 2.

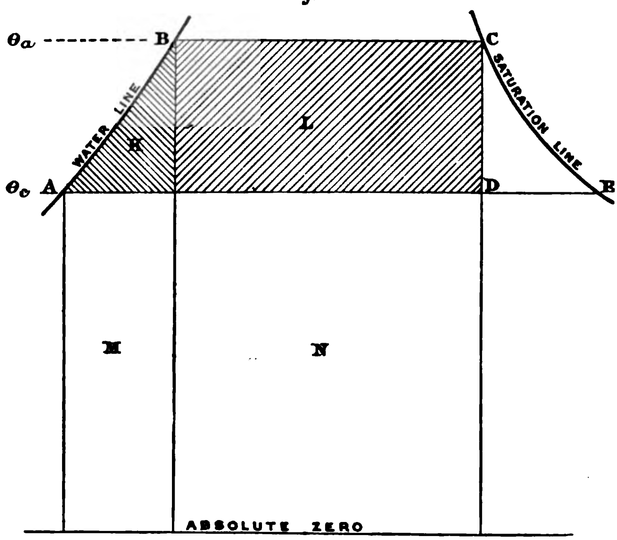
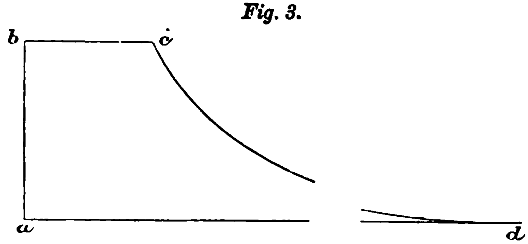


Fig. 3.



along the "water-line" of the $\theta\phi$ chart to the point B, corresponding to the point *b* on the $p\,v$ diagram, and the number of heat-units added is represented graphically by the areas K + M. The heat-supply being continued, the water is gradually evaporated at the higher temperature θ_a, corresponding to pressure p_a. Immediately steam is formed, the piston moves forward under constant pressure, and continues to do so until all the water is evaporated; there is then 1 lb. of saturated steam behind the piston, which has reached

the point of cut-off represented by C on the $\theta\phi$ chart, and by c on the pv diagram. The heat added during this stage, namely, the latent heat, is shown by the area L + N, *Fig.* 2. The heat-supply now ceases, and the piston moves forward under a continually diminishing pressure; in other words, the steam expands adiabatically until the temperature has reached the lower limit θ_e. During this stage the state point travels along the straight line C D on the $\theta\phi$ chart, and along the expansion line cd on the pv diagram. No heat is either added or subtracted during this stage, and when the point D is reached the lb. of H_2O consists of $\frac{AD}{AE}$ lb. of steam and $\frac{DE}{AE}$ lb. of water. The last stage is to condense the steam, namely, $\frac{AD}{AE}$ lb., at constant pressure and temperature by abstraction of heat until the piston has returned to its initial position, and the 1 lb. of H_2O is wholly converted into 1 lb. of water at θ_e. During this stage the state point moves from D to A on the $\theta\phi$ chart, and from d to a on the pv diagram. The heat abstracted is represented by the area M + N. The cycle is now complete, and evidently K + L heat-units have been transformed into work as represented by the pv diagram. The heat represented by (K + L) is the maximum quantity that can be converted into work by a steam-engine working between the limits θ_a and θ_e. In *Fig.* 2, θ_e has been taken as 110° F. and θ_a as 370° F., and it is proposed to retain the same values for the several ideal engines for the sake of obtaining an arithmetical comparison.

The absolute thermal efficiency of the Clausius steam-engine is therefore $\frac{K + L}{K + M + L + N}$, which, with the temperatures chosen, becomes $\frac{318}{1119} = 0 \cdot 284$.

The Carnot cycle can be traced on the $\theta\phi$ chart as follows:—Before the piston begins to move, the cylinder contains 1 lb. of water at θ_a temperature, represented by the point B on the chart, *Fig.* 4, and by the point b on the pv diagram, *Fig.* 5. Heat is then applied, and the water is evaporated at temperature θ_a, corresponding to pressure p_a. When L + N heat-units have been added, all the water has been transformed into steam, and the point C is reached, corresponding to the point of cut-off, c. The steam is now expanded adiabatically to D, after which heat is abstracted at constant temperature θ_e, corresponding to pressure p_e, until the point E is reached, E being vertically below B.

The amount of heat abstracted is represented by the area N. The piston has now attained the position *e*, and the cylinder contains a mixture of steam and water at a temperature θ_e, the weight of steam being $\frac{AE}{AF}$ lb., and the weight of water

Fig. 4.

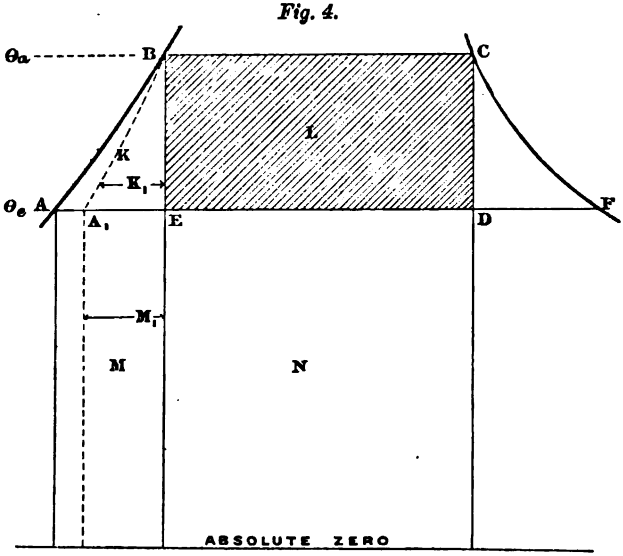
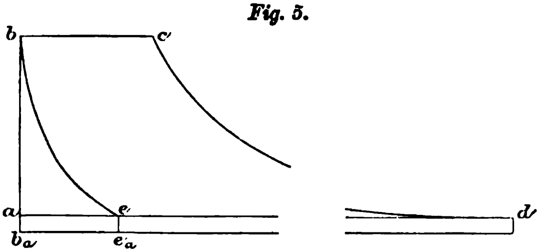


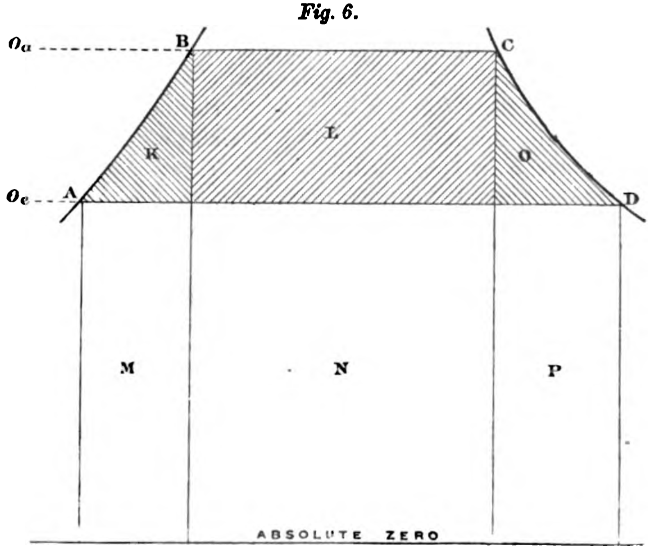
Fig. 5.



being $\frac{EF}{AF}$ lb., together equal to 1 lb. of H_2O. The next step is to compress the steam adiabatically as represented by E B and *e b*. No heat is introduced into or abstracted from the cylinder, but work, represented by the area $b\, b_a\, e_a\, e$, is done, and by means of this work the 1 lb. of H_2O in the cylinder at temperature θ_e is converted into 1 lb. of water at temperature θ_a, and the cycle is completed. The heat supplied during the cycle is

$N + L$, and the heat abstracted is N, so that the portion L is converted into work; hence the absolute efficiency is $\frac{L}{N + L}$, which is evidently greater than the efficiency of the Clausius steam-engine. Therefore, as already pointed out, the Carnot cycle is an unsuitable standard, because it is impossible of realization with the steam-engine as at present constructed, requiring a mechanical feed-heater [1] to produce the portion E B of the cycle. This part of the cycle should not be confounded with the steam compression in an actual steam-engine, because in the latter case only the

Fig. 6.



steam retained in the cylinder is raised to the higher temperature θ_a by the compression, and the remainder of the 1 lb. of H_2O originally contained in the cylinder is exhausted from the cylinder at the lower temperature θ_e, and it, or a corresponding weight of water, has to be raised from θ_e to θ_a in the boiler. Therefore, if an ideal engine expels the proportion $\frac{EF}{AF}$ of its H_2O during the return stroke in the same way that an actual engine does, and gives a *p v* diagram *b c d e*, *Fig. 5*, corresponding to the $\theta\ \phi$ diagram B C D E, *Fig. 4*, heat has to be supplied in the boiler to raise the temperature of the portion

[1] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 236.

$\frac{EF}{AF}$ of the feed-water, and this heat is represented by the areas $K_1 + M_1$. ($A_1 E$ is equal to $AE \times \frac{EF}{AF}$, and the horizontal intercepts of the two curves are in the same proportion.) The absolute efficiency of such an ideal steam-engine is $\frac{L}{K_1 + M_1 + L + N}$, which is evidently not only less than that of the Carnot-cycle engine, but less than that of the perfect steam-engine.

The cycle of the ideal jacketed-engine is shown in *Fig. 6*. It is unnecessary to follow the cycle completely, as it only differs in certain particulars from those previously discussed. During the whole of the expansion from the point of cut-off C, heat has to be introduced into the cylinder to maintain the steam in a state of saturation, and the amount of heat so introduced is represented on the $\theta\phi$ chart by the areas O and P, of which the portion O is converted into work and the remainder rejected, so that the absolute thermal efficiency of the heat supplied by the jacket is only $\frac{O}{O + P}$. The absolute thermal efficiency of the whole cycle is $\frac{K + L + O}{K + M + L + O + N + P}$, which is evidently less than that of the Clausius steam-engine working between the same temperature limits.

In the case of Prof. Osborne-Reynolds' standard, and also in that adopted by Mr. Davey, the expansion continues along the line C R (or cr) until the release-pressure is reached at the point R on the $\theta\phi$ chart, *Fig. 7*, and at r on the pv diagram, *Fig. 8*. The heat added during the expansion is shown on the $\theta\phi$ chart by the areas O_1 and P_1, and it will be observed that of this amount only the small portion O_1 is converted into work. At R (r) the release is effected at constant volume which is represented on the $\theta\phi$ chart by the portion E R of the constant volume-line drawn through R to E. From E to A the exhaust takes place at constant pressure and temperature. The absolute efficiency of this ideal steam-engine is $\frac{K + L + O_1}{K + L + O_1 + M + N + P_1}$; clearly less than that of the ideal jacketed-engine, and *à fortiori* less than that of the Clausius steam-engine, so that the efficiency of an actual engine would be much exaggerated if this cycle were adopted as a standard.

The cycle of the ideal engine, the expansion in which follows the law $pv =$ constant, is shown on the $\theta\phi$ chart in *Fig. 9*. It will be observed that it is necessary, as in the case of the

ideal jacketed-engine, to introduce heat into the cylinder during the whole of the expansion and to a greater extent. The heat so added is represented by the areas S and T, of which S is converted into the work. The absolute thermal efficiency of this ideal engine is $\frac{K + L + S}{K + M + S + L + N + T}$, which is evidently less than that of the Clausius cycle, and it will be noticed that the steam has to be superheated during the whole of the expansion.

Fig. 7.

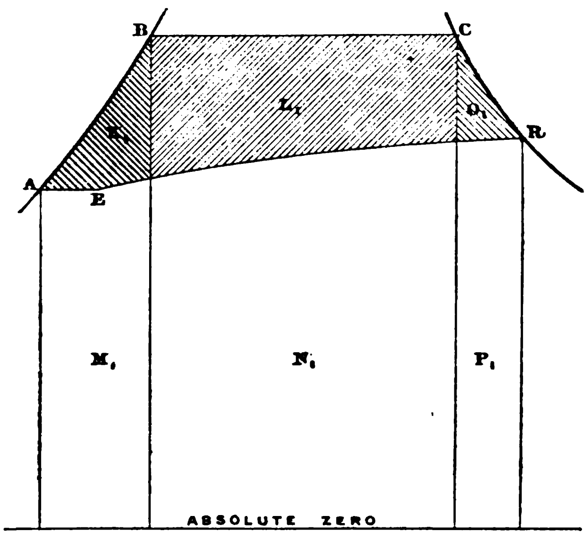
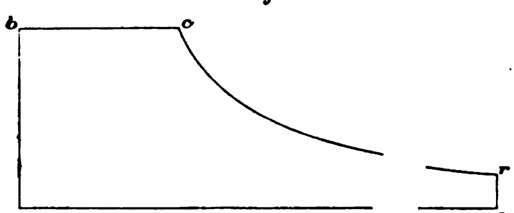


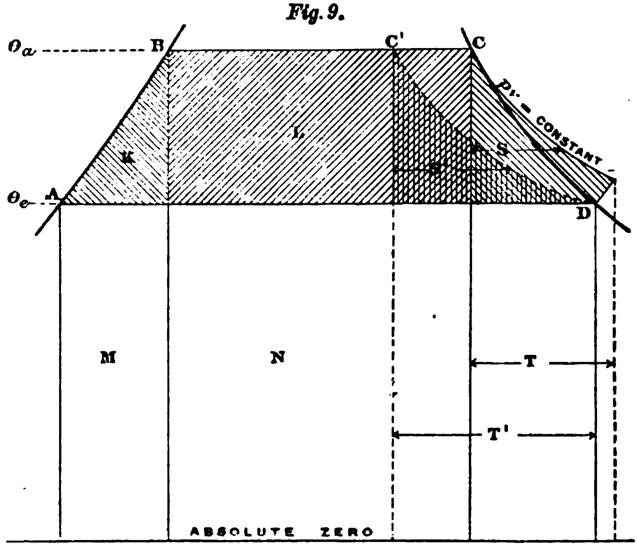
Fig. 8.



In actual engines, in which the expansion-line follows the law $pv =$ constant, there is never any superheat at any point of the expansion; the steam at cut-off must therefore be wet, but it becomes drier as the expansion proceeds, and is, in fact, often nearly dry at release. If quite dry at release, the expansion line

would have to follow the dotted line C′ D on the $\theta\,\phi$ chart, *Fig. 9*, and it is clear that the steam at the point of cut-off C′ must be wet, the dryness fraction being $\frac{C'\,B}{C\,B}$. This wetness of the steam is in general almost entirely due to initial condensation, and the heat so taken out of the steam up to the point of cut-off is $C\,C' \times \theta_a$, and is stored in the water and in the cylinder-walls. The amount of this heat is, however, obviously much less than that required to produce the expansion C′ D, which is S′ + T′, but the deficiency can in great measure be made up by means of

Fig. 9.



jackets. Thus it is that in many engines the expansion approximately follows the law $p\,v$ = constant, and the steam is nearly dry at release.

Data required in Determining the Standard Thermal Efficiency.

The data required to determine the standard thermal efficiency of an actual engine in any given case must next be discussed, and to do this the various lines of the indicator diagram will be considered.

Admission Line.—It might be contended that the higher limit of temperature (θ_a) ought to be that corresponding to the boiler-pressure, but it is to be observed that the steam-pressure in the

cylinder up to the point of cut-off will always be less than the boiler-pressure. This defect in pressure is in part due to throttling in the valve-passages,[1] and in part to the energy required to put the steam in motion in the steam-pipes. The former part of this defect is due to the engine, and any resulting loss is rightly charged to the engine, but the latter is due to the steam-pipes, and ought not to be charged against the engine. Account should, however, be taken of the energy in the steam due to its velocity; but if the steam-pipes are of sufficient size this energy is so small a percentage that it can be neglected. Thus if the velocity of the steam is 50 feet per second the energy due to velocity is 0·05 B. T. U. per lb., or only about 0·005 per cent. of the total energy in the steam. It thus appears that the higher limit of temperature ought to be taken as the temperature of the steam in the steam-pipe close to the admission into the engine, that is, at the engine stop-valve.

Expansion.—The expansion in the Clausius steam-engine is continued to the back pressure; in an actual engine, however, there is loss in respect of effective horse-power if the expansion is carried beyond the pressure (referred to the low-pressure piston) required to drive the engine itself. A standard, in which the expansion is carried down to the back pressure would therefore tend towards the use of engines too large for their work. It would be a mistake to establish a standard that would tend to such a result. On the other hand, if the expansion is limited so that the release pressure is equal to the back pressure plus the mean pressure corresponding to the friction of the engine, a premium is, so to speak, awarded to a stiff engine instead of a penalty, which is clearly not right. Moreover, the standard, instead of being dependent only on the range of temperature, is made to vary with the stiffness of the actual engine. Both these objections can be in great measure obviated by agreeing that the expansion in the standard of comparison shall be carried down to the back-pressure plus a pressure to be decided upon, a suggestion originally made by Mr. Macfarlane Gray.[2] This additional pressure should be somewhat less than the mean pressure required to drive the most mechanically efficient engine it is reasonably possible to make, and the Author suggests that this pressure should be taken at 0·15 atmosphere, which corresponds to a mechanical efficiency of 93·5 per cent. when the mean pressure referred to the low-pressure piston is 34 lbs. per

[1] Radiation and conduction losses in the steam-pipes, &c., cause condensation of a portion of the steam, and the water thus produced is supposed to be drained off and allowed for in reckoning up the feed.

[2] Minutes of Proceedings Inst. C.E., vol. cxiv. pp. 73, 102 and 103.

square inch.[1] The reduction in the work done by the standard of comparison by thus limiting its expansion is shown in *Figs. 10* and *11*, both for a condensing, and for a non-condensing engine. It will be observed that the reduction is far less for the latter than for the former,[2] and this leads to another advantage of limiting the expansion of the steam in the standard engine as suggested, for if the Clausius perfect steam-engine is taken as the standard, that is, if the expansion is continued to the back pressure, a condensing engine, if properly proportioned to its work, must of necessity have a considerably less standard thermal efficiency than a non-condensing engine, whereas if the expansion is limited a more real comparison is established between the two varieties of engine.

Fig. 10.

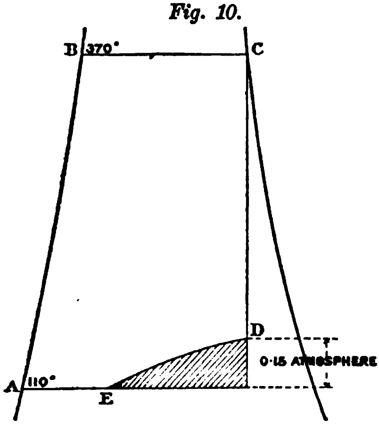
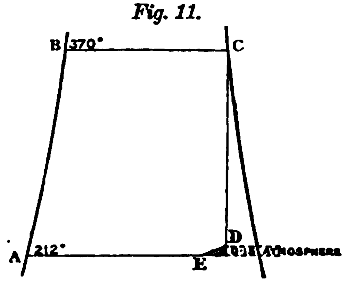


Fig. 11.



Back Pressure.—The view may be taken that for a non-condensing engine the back pressure, and the corresponding lower limit of temperature, should be taken at atmospheric pressure, and that for a condensing engine a limit should be fixed, based on some such grounds, that the gain due to improved water-consumption, owing to improvement in vacuum, is equal to the increase in cost of driving the air-pumps, etc. This degree of vacuum must vary in every case; possibly, however, not to any very great extent.

Another view may however be taken, namely, that as regards a condensing engine, a defect in vacuum outside the engine is the fault of the condensing arrangements, and that it would be as

[1] Mr. Michael Longridge also takes this view of the matter. See his remarks on Mr. Davey's Paper on "Steam-Engine Economy," Minutes of Proceedings Inst. C.E., vol. cxxii. p. 32.

[2] Minutes of Proceedings Inst. C.E., vol. cxiv. pp. 10 and 56.

reasonable to take the lower limit at, say, 110° F. for a non condensing engine, which is hampered by the atmospheric pressure, as it would be to take the same limit for a condensing engine which is hampered by a back pressure of 3 lbs. (140° F.) due to a defective air-pump or condenser, or, as in many cases, due to warm injection water. At any rate, it is only a question of degree.

The object of the standard under discussion is to compare the actual engine with an ideal steam-engine working under the same conditions of temperature, and to make this comparison an accurate one the lower limit of temperature should be that in the exhaust just outside the engine, a temperature which would have to be observed. In this manner defects in the exhaust pipes, or in the condensing arrangements, are not reckoned against the engine, and thus a true ratio is obtained of the transformation of heat into work effected by the actual engine proper, as compared with what is possible by the standard working under the same conditions. This way of taking the lower limit of temperature also includes the not unusual case of an engine working against a considerable back pressure, and also the less usual case of working at a high elevation in an atmosphere of less pressure.

Compression.—There appears to be an unanimity of opinion that the standard of comparison should have no clearance, and therefore no compression. Such an engine is of course practically unattainable, but it is possible with actual engines to have the clearance so small that the gain by expunging the clearance altogether is minute. The compression line of the standard should therefore follow the water line A B on the $\theta\ \phi$ chart.

Proposed Standard of Comparison.

The preceding considerations tend to indicate the following definition of the most satisfactory ideal steam-engine for a standard of comparison.

The heat is received into the feed-water at varying temperatures, gradually increasing from the temperature in the exhaust just outside the engine to the temperature of the steam at the engine stop-valve. The evaporation is considered to take place at a constant temperature equal to that at the engine stop-valve, and dry saturated steam is used. The expansion is adiabatic and is carried to a pressure equal to 0·15 atmosphere more than the pressure in the exhaust pipes immediately outside the engine. The lower limit of temperature at which the heat is rejected is constant, and is that corresponding to the pressure in the exhaust

pipe of the actual engine at the outlet from the engine. There is no compression and no clearance.

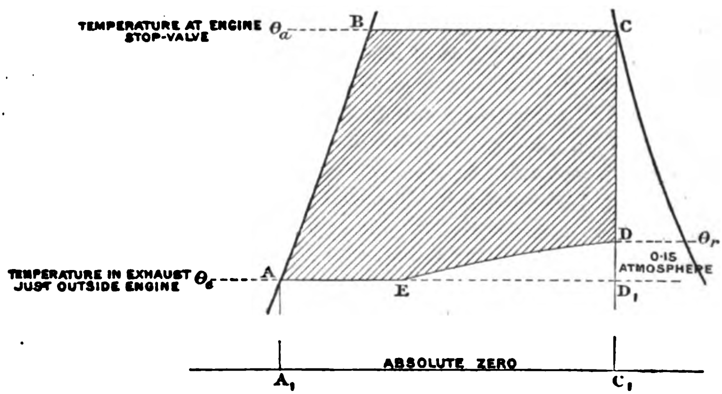
The Author suggests this ideal steam-engine as the standard of comparison, and its cycle is graphically shown on the $\theta\,\phi$ chart in *Fig. 12*, by the lines A B, B C, C D, D E, and E A. It is the Clausius perfect steam-engine, with a certain portion of the toe of the *p v* diagram cut off.

The absolute thermal efficiency of this standard steam-engine is $= \frac{\text{area ABCDE}}{\text{area A}_1\text{ABCC}_1}$, and in symbols it is expressed by—

$$\frac{\left(\theta_a - \theta_r\right)\left(1 + \frac{L_a}{\theta_a}\right) - \theta_r \log_e \frac{\theta_a}{\theta_r} + \frac{144\,(p_r - p_e)\,V_r}{778}}{L_e + \theta_a - \theta_e},$$

where θ_a, θ_r and θ_e are respectively the absolute temperatures of

Fig. 12.

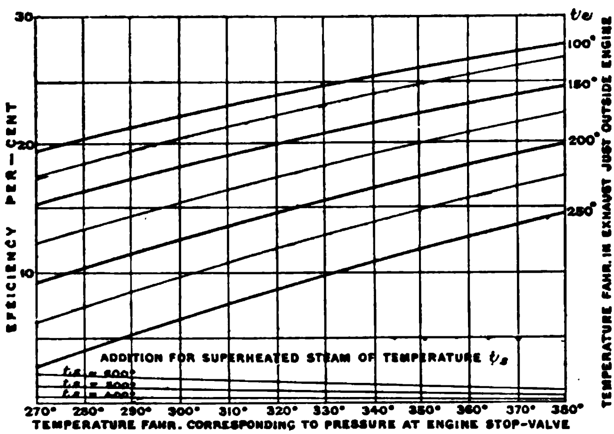


admission, release and exhaust, L_a is the latent heat at temperature θ_a, p_r and p_e are respectively the absolute pressures at temperatures θ_r and θ_e ($p_r - p_e = 0{\cdot}15$ atmosphere), and V_r is the volume of steam at temperature θ_r.

As will be evident from an examination of the above formula, the calculations required to obtain the absolute thermal efficiency of the proposed standard are of considerable length and complication, for it will be noticed that θ_r is so related to θ_e that the difference of the pressures corresponding to these temperatures is 0·15 atmosphere, and that V_r is the volume of 1 lb. of H_2O after adiabatic expansion from θ_a to θ_r. Possibly the expression might

be thrown into a more workable form, but the Author has not made any attempt to do this, because a solution can readily be obtained by means of the $\theta\,\phi$ chart, as explained in Appendix I. Even by this method, however, the calculations are considerably longer than those required to obtain the absolute thermal efficiency of the Carnot cycle, and this is possibly one of the reasons why the Carnot cycle has been so generally adopted as a standard. To obviate this objection to the standard engine proposed, the Author has prepared a set of curves, which are given in *Fig. 13*, by means of which the absolute thermal efficiency of the standard can be read off without any calculation.

Fig. 13.



CURVES OF ABSOLUTE THERMAL EFFICIENCY OF PROPOSED STANDARD ENGINE WITH DIFFERENT ADMISSION- AND EXHAUST-TEMPERATURES, AND WITH SATURATED AND SUPERHEATED STEAM.

The following numerical example shows how to obtain the absolute thermal efficiency and the standard thermal efficiency of an actual engine working under the following conditions:—

Admission-temperature, $\theta_a = 370°$; exhaust-temperature, $\theta_e = 110°$; feed-water per I.HP., 13·4 lbs.

The amount of heat required to produce saturated steam at 370° F. at constant pressure from a temperature of 110°, is 1,117 B.T.U., but 42·4 × 60 B.T.U. correspond to 1 HP. per hour; hence absolute thermal efficiency of actual engine $= \dfrac{42 \cdot 4 \times 60}{1{,}117 \times 13 \cdot 4}$ = 17 per cent.

From *Fig. 13* it appears that the absolute thermal efficiency of the standard engine is 26·8 per cent. Hence the standard thermal efficiency of the actual engine is $\frac{17}{26 \cdot 8} = 63 \cdot 5$ per cent.

Although probably unnecessary, it may be well to state that the standard engine is assumed to be free from mere internal defects of design; for instance, there is no clearance in the cylinders or ports, no incomplete expansion by reason of cylinder dimensions restricted for practical convenience; no back pressure due to friction in exhaust ports, or passages within the engine itself, and no losses from either condensation, radiation, conduction or leakage.

The relation which the various ideal engines bear to each other is clearly brought out in the following Table, in which an actual engine working between the temperature limits of 370° and 110° F., and of which the absolute thermal efficiency is 17 per cent., is compared with the other standards.

Description.	Absolute Thermal Efficiency.		Standard Thermal Efficiency of actual Engine compared with the various ideal Engines.
	On $\theta\ \phi$ Chart.	Of Numerical Example.	
Actual engine	..	17·0	
Clausius perfect steam-engine .	$\frac{K+L}{K+M+L+N}$	28·3	60·6
Carnot cycle heat-engine . .	$\frac{L}{M+N}$	31·3	54·4
Ideal jacketed-engine . . .	$\frac{K+L+O}{K+M+O+L+N+P}$	25·9	65·7
Reynolds ideal engine . . .	$\frac{K+L+O_1}{K+M+O_1+L+N+P_1}$	22·5	75·6
Proposed standard ideal engine	..	26·8	63·5

As a summary it appears that there are three different thermal efficiencies, which are useful when considering the thermal performance of an engine:—

I. The absolute thermal efficiency—

$$\frac{\text{Heat-units converted into work by the actual engine}}{\text{Heat-units supplied to the engine}}.$$

II. The standard thermal efficiency—

$$\frac{\text{Heat-units converted into work by the actual engine}}{\text{Heat-units which the corresponding standard steam-engine can convert into work}},$$

or—

$$\frac{\text{The absolute thermal efficiency of the actual engine}}{\text{The absolute thermal efficiency of the corresponding standard engine}}.$$

III. The type thermal efficiency—

$$\frac{\text{Heat-units converted into work by the actual engine}}{\text{Heat-units which the corresponding ideal steam-engine of the same type can convert into work}},$$

or—

$$\frac{\text{The absolute thermal efficiency of the actual engine}}{\text{The absolute thermal efficiency of the corresponding type standard}}.$$

The uses of the absolute thermal efficiency and of the standard thermal efficiency have already been mentioned, and in the Author's opinion both these efficiencies should be stated in reporting trials of engines. The type thermal efficiency is only useful to the designer of the particular type in question, and has therefore not further been discussed.

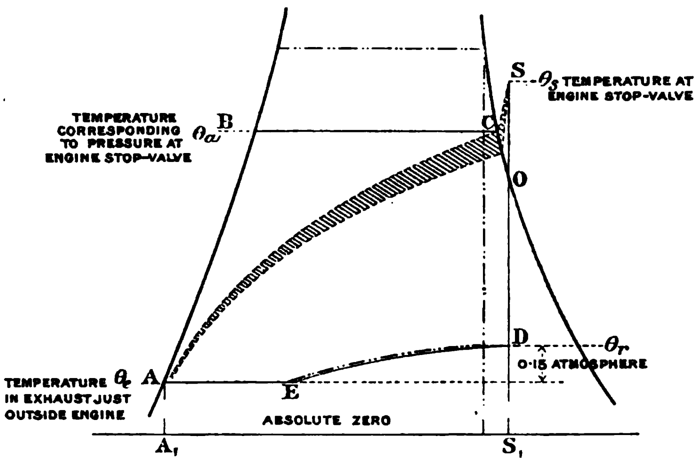
Standard of Comparison for Superheated Steam-Engines.

The absolute thermal efficiency is as applicable to a superheated steam-engine as it is to a saturated steam-engine. As regards the standard thermal efficiency, the perfect superheated steam-engine will be the same in principle as the perfect saturated steam-engine of Clausius, and it only remains to find what is its absolute thermal efficiency.

Returning to first principles, let the ideal cylinder contain 1 lb. of water at temperature θ_e and pressure p_e. On the application of heat, the temperature of the water will be raised until the pressure p_a is reached, precisely as in the case of the saturated steam-engine, its state being then defined by B on the $\theta\,\phi$ chart, *Fig. 14.* On further application of heat to the cylinder, the water is evaporated at constant pressure p_a until the point C, representing saturation is reached, then the state of the steam follows the constant pressure-line C S (pressure p_a) until the temperature of superheat, θ_s, is reached at the state point S. The cylinder then contains 1 lb. of superheated steam at pressure p_a and temperature θ_s which has been formed at the constant pressure p_a according to the graph A B C S, and the heat required

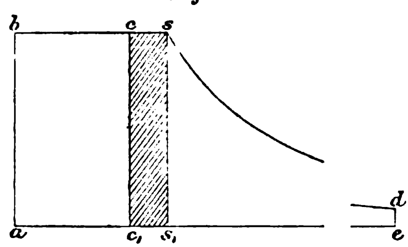
for this process is represented by the area below this graph bounded by the verticals through A and S. The heat required to superheat the steam is represented by the area below C S, bounded by the verticals through C and S. In the *p v* diagram *Fig. 15* the corresponding points *c* and *s* lie on the same horizontal line at

Fig. 14.



pressure p_s and the area $c\,s\,c_1\,s_1$ is the work done on the piston during the process of superheating at constant pressure, and is represented on the $\theta\,\phi$ chart by the shaded area enclosed between the constant volume lines drawn through C and S.

Fig. 15.



In determining the temperature of superheat to be debited against the actual engine of which the standard thermal efficiency is required, it should be observed that the steam will reach the engine with less superheat than it had on leaving the superheater, and it is of course only this lesser superheat that should be charged

against the engine. That is to say, the temperature θ_s should be the steam temperature just outside the engine stop-valve. An addition ought to be made for the energy contained in the steam due to its velocity in the steam-pipe, but as already seen, the proportionate amount of this energy is so small that it may be neglected, provided the steam-pipe is of sufficient dimensions, so that the velocity of the steam does not exceed, say, 50 feet to 60 feet per second.

To continue the cycle: at S adiabatic expansion commences, represented by the straight line S D, on the $\theta\ \phi$ chart (*Fig. 14*), and by *s d*, on the corresponding *p v* diagram, and continues to the point D, that is, until a pressure of 0·15 atmosphere above the exhaust pressure has been reached, adopting the same release pressure as in the case of the saturated steam-engine.[1] It will be noticed that at the point O the expansion crosses the saturation line, and from this point onwards, therefore, the steam is wet. The remainder of the cycle is the same as in the case of the standard saturated steam-engine. It will be seen that the standard for superheated steam converts into work the heat-units represented by the area A B C S D E, so that its absolute thermal efficiency is $= \dfrac{\mathrm{ABCSDE}}{\mathrm{A_1ABCSS_1}}$.

The following numerical example is worked out as an illustration, the temperature of steam at entrance to the engine being 420° F., the pressure, 150 lbs. absolute, and the temperature of exhaust, 110° F.

The $\theta\ \phi$ diagram of the standard of comparison for this numerical example is given in *Fig. 14*, and it is found that the area A B C S D E is equal to 299 B. T. U., and that the area A_1 A B C S S_1 is 1,143 B. T. U., so that the absolute thermal efficiency is $\dfrac{299}{1{,}143} =$ 26·2 per cent.

This result can, however, be more readily obtained by means of the curves in *Fig. 14*, as the following will show.

The temperature of saturated steam corresponding to a pressure of 150 lbs. absolute is 358° F.; and from the curves (*Fig. 13*) the absolute thermal efficiency of the saturated steam-engine with an admission temperature of 358° and exhaust temperature of 110° is found to be 0·260. But the addition read off the curves marked "superheated steam" is 0·002; so that the absolute thermal

[1] In the perfect superheated steam-engine the expansion continues to the back pressure.

efficiency of this superheated steam-engine is 0·262, or 26·2 per cent. as before.

As already shown, the heat required to produce superheated steam at 420° F., and 150 lbs. pressure from 110° F. is 1,143 B.T.U. If this energy were used to make saturated steam the pressure would be 448 lbs. and the temperature 456° F., and the portion of this energy that the corresponding standard of comparison for saturated steam could convert into work is 363 B.T.U., shown by the dotted diagram in *Fig. 14.* It has just been shown, however, that the standard of comparison for superheated steam converts less than this into work; namely, 299 B.T.U., from which it appears that the superheated steam-engine does not make as good use of the heat as the saturated steam-engine, so far as the standards of comparison are concerned.

Another numerical example will illustrate this point further. One of the trials of the Schmidt engine by Professor Schröter[1] gave the following results: admission temperature $t_s = 650°$ F.; pressure $= 185$ lbs. absolute per square inch; exhaust temperature $t_e = 100°$ F.; feed-water per I.HP. per hour 10·2 lbs. From these figures it works out that the absolute thermal efficiency of the actual engine was $\frac{2,543}{12,820}$, or 19·9 per cent. But the absolute thermal efficiency of the standard superheated steam-engine working under the same conditions is 29·1 per cent., so that the standard thermal efficiency of the Schmidt engine in this experiment is $\frac{19 \cdot 9}{29 \cdot 1}$, or 68·5 per cent.

The absolute thermal efficiency of the Carnot cycle heat-engine, working under the same range of temperature, will be found to be 49·5 per cent., much greater, it will be noticed, than that of the standard superheated steam-engine. *Fig. 14* shows the reason, namely, how small a portion of the heat is supplied in the neighbourhood of the higher temperature.

Commercial Criterion of Engine Economy.

The two efficiencies which have been considered in the Paper, namely, the absolute thermal efficiency and the standard thermal efficiency, apart from being the basis on which to compare various engine-trials, are principally useful to the designer of steam-engines, especially the standard thermal efficiency, as it points

[1] See *Engineering*, vol. lix. p. 391.

out the extent to which an actual engine fails to reach perfection. The usual commercial criterion as to an engine's thermal economy is, however, the number of pounds of feed-water per hour per I.HP., and although this measure of the economy is not accurate, because the number of heat-units per lb. of steam depends upon the pressure, yet the error is inconsiderable in the case of saturated steam for the usual ranges of pressure used; thus, 1,182 B.T.U. are required to produce steam at 100 lbs. absolute pressure, and 1,198 B.T.U. are required to produce steam at 200 lbs. absolute pressure, in both cases from 32° F., so that the error in reckoning in lbs. of feed per I.HP. per hour is only 1·4 per cent.

With superheated steam, however, the error may be considerable. Supposing, for instance, that steam at 185 lbs. absolute pressure is superheated to 650° F.: to do this, 132 B.T.U. per lb. have to be added, so that altogether 1,328 B.T.U. per lb. are required, and the error in reckoning in lbs. of feed-water per I.HP. is no less than 12·4 per cent. when compared with saturated steam at 100 lbs. pressure. Thus if it is found by measurement that an engine using superheated steam at 650° F. requires 10·2 lbs. of feed-water per I.HP., this, so far as heat expenditure is concerned, which of course means coal-consumption, is equivalent to 11·46 lbs. of feed-water when compared with an engine using saturated steam at 100 lbs. pressure.

	Lbs. of Feed-Water per I.HP. per Hour.	Apparent Comparison.	Heat-Units per I.HP. per Hour from 32° F.	True Comparison.
Saturated steam-engine:—				
100 lbs. per square inch pressure	16·0	1·57	18,910	1·39
200 lbs. " " " "	12·0	1·18	14,380	1·06
Superheated steam-engine:—				
185 lbs. per square inch pressure, superheated to 650° F.	10·2	1·00	13,550	1·00

All condensing.

The true criterion of an engine's economy is of course heat-units required per horse-power-hour, or per kilowatt-hour, as was pointed out by Mr. Mair-Rumley in his Paper "On the Independent Testing of Steam-engines and the Measurement of Heat used," where he advocates[1] stating the number of heat-units required per I.HP.

[1] Minutes of Proceedings Inst. C.E., vol. lxx. p. 315, and Table I, line 65 (Pamphlet Edition only).

per hour reckoned from 32° F. Thus, in the case of the superheated steam-engine above referred to, 13,550 B.T.U. are required per I.HP. per hour,[1] and the comparison of three engines by the two methods would be as shown in the Table on the preceding page.

The Paper is accompanied by thirteen drawings from which the *Figs.* in the text have been prepared.

[1] On the assumption that specific heat of steam is 0·48—a figure which is open to some doubt.

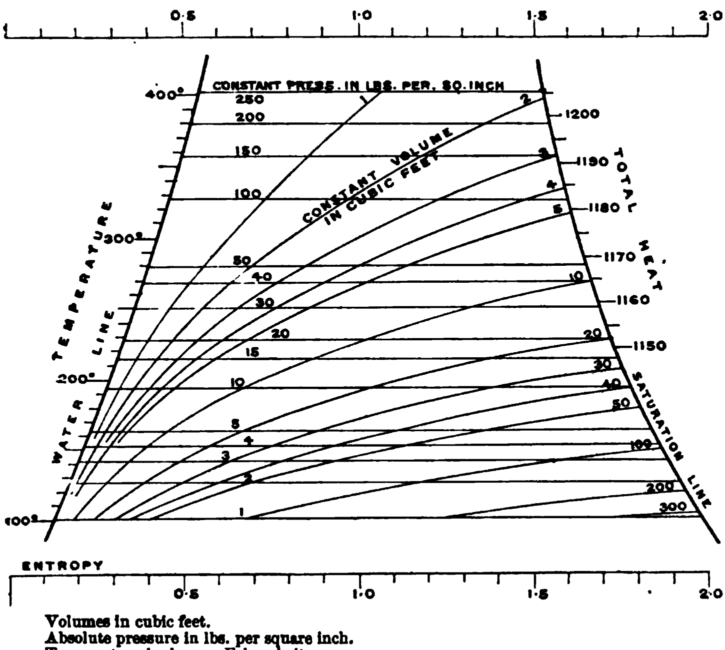
APPENDIXES.

APPENDIX I.

USE OF THE $\theta\phi$ CHART FOR FINDING THE ABSOLUTE THERMAL EFFICIENCY OF THE PROPOSED STANDARD ENGINE.

To find the absolute thermal efficiency of the proposed standard engine readily by means of the $\theta\phi$ chart, it is necessary to draw constant-pressure and constant-volume lines on the chart as shown in *Fig. 16*. To illustrate the method, it is proposed to find the absolute thermal efficiency of the standard

Fig. 16.



Volumes in cubic feet.
Absolute pressure in lbs. per square inch.
Temperature in degrees Fahrenheit.

One British thermal unit is represented by the area of a square of side equal to 0·115 inch, or 0·0133 square inch.

$\theta\phi$ CHART FOR 1 LB. OF H_2O.

for saturated steam when $\theta_a = 370° + 461$, and $\theta_e = 110° + 461$. Referring to *Fig. 12*, a vertical is drawn through the intersection, C, of the 370° temperature line with the saturation line; this vertical represents adiabatic expansion. From the intersection, D_1, of this vertical with the 110° temperature line, a pressure of 0·15 atmosphere (2·2 lbs. per square inch) is plotted back by means of the constant-pressure lines, and so the point D is determined, giving the

temperature at release $\theta_r = 608°$ F., and the volume at release $V_r = 82 \cdot 5$ cubic feet; thus all the data required for the formula given at page 200 have been found.

A graphic method can, however, be followed by drawing in the constant-volume line, D E, and determining the area, A B C D E in any convenient manner.

It is, however, easier in practice to proceed thus. The area A_1 A B C C_1 is equal to the total heat of steam at C, less the water-heat at A,

$$= 1{,}195 - 110 + 32.$$
$$= 1{,}117 \text{ B.T.U.}$$

The area A_1 A D_1 C_1 is equal to $\theta_e \times$ A D_1, and A D_1 can be measured off the entropy scale, and is found to be $= 1 \cdot 402$. Therefore

$$\text{Area } A_1 A D_1 C_1 = (110 + 461) \times 1 \cdot 402 = 801 \text{ B.T.U.}$$
$$\text{Hence area } A B C D_1 = 1{,}117 - 801$$
$$= 316 \text{ B.T.U.}$$

The area E D D_1 is now measured by a planimeter, or otherwise, and is found to equal 17 B.T.U., so that

$$A B C D E = 316 - 17$$
$$= 299 \text{ B.T.U.}$$

and finally, the absolute thermal-efficiency of the standard $t_a = 370°$, and $t^e = 110°$.

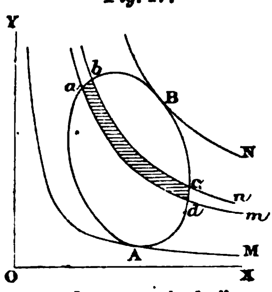
$$= \frac{299}{1{,}117} = 26 \cdot 8 \text{ per cent.}$$

Evidently the same method is applicable to find the absolute thermal efficiency of the standard for the superheated steam-engine.

APPENDIX II.

The efficiency of the fluid in heat-engines in general has been investigated by Rankine.[1] The Author would like to show that Rankine's result can readily be obtained for steam-engines by means of Mr. Macfarlane-Gray's $\theta\,\phi$ chart. *Fig. 17* is a reproduction of Fig. 101 in Rankine's "Manual," and in connection with this Fig. he says:—"Draw a pair of adiabatic lines, A M, B N, touching the closed line in A B respectively, and indefinitely produced in the direction of O X. Then throughout the process represented by the part A *a b* B of the diagram, the fluid is receiving heat, and throughout the process represented by the part B *c d* A is rejecting heat. Cut an indefinitely narrow band from the diagram by any pair of indefinitely-close adiabatic lines *a d m*, *b c n*, corresponding to the thermodynamic functions ϕ, $\phi + d\,\phi$ respectively."

Fig. 17.



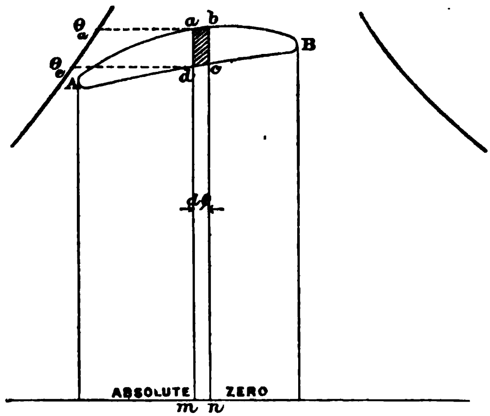
Rankine treats *a b c d* as the diagram of an elementary engine, which in the previous paragraph (265) he defines as an engine in which the reception of heat by the fluid takes place wholly at one absolute temperature (θ_a) and its

[1] "Manual of the Steam-Engine and other Prime Movers," paragraph 266.

rejection at another absolute temperature (θ_e); in other words, an elementary engine is an engine following the Carnot cycle.

Fig. 18 shows the $\theta\phi$ diagram corresponding to the pv diagram $\mathrm{A}\,a\,b\,\mathrm{B}\,c\,d$ in *Fig. 17*. Considering the elementary engine whose $\theta\phi$ diagram is $a\,b\,c\,d$ (which corresponds to the pv diagram $a\,b\,c\,d$, *Fig. 16*), it is clear that the heat supplied is $a\,b\,n\,m$, and the heat utilized is $a\,b\,c\,d$, so that the thermal efficiency of this small portion of the whole engine is $\frac{a\,b\,c\,d}{a\,b\,n\,m}$, which is equal to $\left(\frac{(\theta_a - \theta_e)\,\delta\,\phi}{\theta_a\,\delta\,\phi}\right) = \frac{\theta_a - \theta_e}{\theta_a}$, which is a proof, if a proof were required, that the element of the engine is an "elementary" engine; that is, its cycle is the Carnot cycle. It will be noticed how easily this result is obtained from the $\theta\phi$ chart.

Fig. 18.



Further, since the heat utilized by the element of the engine is $(\theta_a - \theta_e)\,d\phi$ the heat utilized by the whole engine is,

$$\int_{\phi_A}^{\phi_B} (\theta_a - \theta_e)\,d\,\phi,$$

where ϕ_A and ϕ_B are the entropies at A and B. The total heat supplied to the engine is clearly

$$\int_{\phi_A}^{\phi_B} \theta_a\,d\,\phi,$$

so that the absolute thermal efficiency of the engine is

$$\frac{\int_{\phi_A}^{\phi_B} (\theta_a - \theta_e)\,d\,\phi}{\int_{\phi_A}^{\phi_B} \theta^a\,d\,\phi}$$

the result given by Rankine, and from which the absolute thermal efficiency of all the ideal engines referred to in the Paper can be obtained.

The cycle of the element of the engine can be followed on the $\theta\,\phi$ chart as follows:—Let the piston be considered at the moment it is in the position represented by *a*, *Fig. 17*. The space in the cylinder behind the piston now contains 1 lb. of H_2O in the condition represented by the state point *a* on the $\theta\,\phi$ chart, that is, the proportion of steam to water, the pressure, temperature and volume can be read off the $\theta\,\phi$ chart when mapped out with constant volume and constant pressure lines, etc., as in *Fig. 16*. An element of heat, namely, $\theta_a\,d\,\phi$, is now introduced, and under its influence the piston moves to *b*, *Fig. 17* and the state-point to *b*, *Fig. 18*. The heat-supply now ceases, and the piston moves forward owing to the expansion of the steam; the expansion line is adiabatic, represented by *b c* both on the *p v* diagram and on the $\theta\,\phi$ chart. When the piston reaches *c* an element of heat, $\theta_e\,d\,\phi$, is abstracted, and the piston moves back to *d*, *Fig. 17*. The piston is now forced back, doing work on the 1 lb. of H_2O and compressing it adiabatically along *d a* in *Figs. 17* and *18*. When *a* is reached the cycle of the element of the engine is complete, and the net work done is represented by *a b d c*.

DISCUSSION.

Discussion.

Sir Benjamin Baker, K.C.M.G., President, said in his Presidential Address[1] he had suggested that the Institution might do useful work in securing uniformity, if possible, in engineering problems of different kinds. He thought the Paper was a distinct advance in that direction, because, no doubt, considerable inconvenience was occasioned and a great amount of time wasted in consequence of there being no standard for comparison in experimental investigations of steam-engines. If, as a result of the Author's very able Paper and the discussion upon it, some standard could be agreed upon by the members, to be known as the Institution Standard, he was sure the Author would think the trouble he had bestowed on his Paper would be amply justified. He had great pleasure in proposing a vote of thanks to the Author. Sir B. Baker.

Captain H. Riall Sankey thanked the President for his kind remarks and the members for their reception of the Paper. He Capt. Sankey.

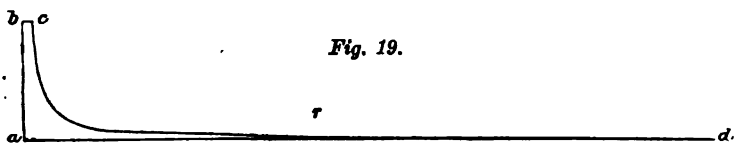


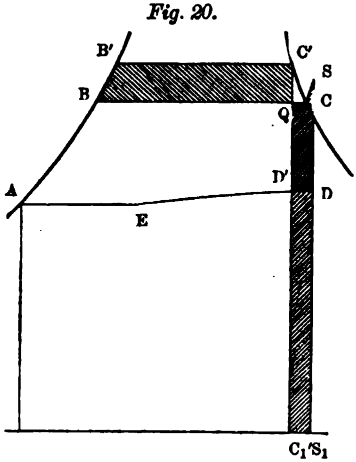
Fig. 19.

wished to call attention to the *p v* diagram, *Fig. 19*, which was *Fig. 3* drawn out to full length. The point at which he proposed to cut off the toe of the diagram was at 0·15 atmosphere above the back-pressure. Looking at this diagram, one was tempted to think that it would be almost better to cut off more of the toe, and as there was a certain advantage in round numbers he suggested that it should be cut off at 0·2 atmosphere above the back-pressure. The obvious reason for choosing a fraction of an atmosphere instead of so many pounds per square inch was to make the standard universally applicable. The shaded part of *Fig. 19*, *i.e.*, from *r* to *d*, corresponded in area to the shaded part of *Fig. 10*. Although probably unnecessary, he thought it well to mention that the shaded areas on the various $\theta\,\phi$ diagrams were no indication of the efficiency of the corresponding ideal engines. For instance the area L in *Fig. 4* was less than K + L in *Fig. 2*. Nevertheless,

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 1.

Capt. Sankey. the latter was the less efficient engine because it was a matter of the ratio of the heat converted into work to the heat supplied. In the first case this ratio was $\frac{L}{N}$, and in the second case it was $\frac{K + L}{K + M + L + N}$. It was stated in the Paper that the standard superheated steam-engine did not make so good a use of the heat as the standard saturated steam-engine. A further diagram, *Fig. 20*, had been prepared to show that point more clearly. The area A_1 A B C S S_1 represented the heat given to the standard superheated steam-engine, and A_1 A B′ C′ C_1' an equal quantity of heat given to the standard saturated steam-engine; hence the shaded areas B B′ C′ Q and Q C S S_1 C_1' were equal. The work done by the superheated steam-engine was A B C S D E, and that by the saturated steam-engine was A B′ C′ D′ E, which was obviously greater than the former.[1] Some terms were used in the Paper that he would like to define a little more closely to prevent confusion. He had used the expression "ideal engine" in the sense of a theoretical engine, that gave any desired indicator or *p v* diagram, and he had not used it in the sense of a perfect engine; it might be applied to any heat-engine whatever, not only to a steam-engine. The perfect steam-engine was the particular ideal steam-engine which utilized the greatest amount of the heat supplied; it was also known as the "Clausius steam-engine." He had used the term "standard engine" in the special sense of the particular ideal engine, which, he hoped, might be chosen as the standard of comparison. At p. 200 there was a formula, in which, it would be observed, he had used 778 as the Joule equivalent, in accordance with the latest determinations of Messrs. Griffiths, Clark, and others. Corresponding to that, he had used 42·4 B.T.U. as the equivalent of 1 HP. per minute, instead of the more usual figure, 42·75.

Fig. 20.



Mr. Mair-Rumley. Mr. J. G. MAIR-RUMLEY had great pleasure in listening to the Paper and looking at the diagrams, which conveyed in the

[1] D E and D′ E′ are not shown separate in this figure as they nearly coincide (see *Fig. 14*).

Author's best manner the absolute inwardness of the $\theta\phi$ diagram. The $\theta\phi$ diagram was well known from the work of Mr. Macfarlane Gray and the late Mr. Willans, but he thought the Paper showed more clearly the applicability of the diagram to a standard steam-engine than anything that had yet appeared in the Proceedings of the Institution. Engines had been compared with the Clausius standard by Mr. Willans, and the standard now adopted by the Author was the Clausius standard with the toe taken off. He believed there would be not only in England, but in all parts of the world, a good deal of discussion as to the right amount of toe to be taken off, and whether any should be taken off at all. For comparison he believed it was better to take, as Mr. Willans had done, the entire Clausius standard by itself, or, better still, the Carnot cycle. In the Clausius standard, or in the standard of Carnot, there was the curious fact that the smaller the number of expansions the more nearly the standard was approached, so that an engine that was not really economical with regard to the amount of steam it used might approach more nearly to the Clausius or the Carnot cycle than if it were an engine with a higher rate of expansion and a better rate of duty. For that reason it seemed that the best basis for comparison was to compare the heat-unit expended per HP. with the thermal equivalent of work done. Having this efficiency it was only necessary to divide the number 42·75 (the thermal equivalent of 1 HP.) by the efficiency to obtain the heat used, and therefore the lbs. of steam, and from that could be obtained the amount of fuel if it was known what heat the fuel would give. It appeared much better to have the absolute efficiency of the engine on that basis than to have it in a form based on an assumption of cutting off so much of the toe of a theoretical diagram. In making engine trials with several rates of expansion according to the basis laid down by the Author, the lower the rate of expansion the better the engine would appear in regard to efficiency. It was necessary for users to know when a certain efficiency was given, how the exact amount of heat and steam, and if desired also the amount of coal used, could be calculated from it without trouble. That could not be done with an ideal standard because it was not known what an ideal standard was. It was best, therefore, for practical purposes, to compare the amount of heat used by the engine with the thermal equivalent of the indicated work; and for theoretical purposes the Carnot cycle should be adopted. Mr. Mair-Rumley.

Mr. Henry Davey thought the Author had rendered great service to the Institution by his lucid Paper. The subject Mr. Davey.

Mr. Davey. was an important one, and although many engineers, with Mr. Mair-Rumley, considered that one standard was sufficient, he was not himself of that opinion, and he would give a practical example illustrating his view. He had in mind two engines, one working with 30 lbs. or 35 lbs. per square inch and expanding to a very moderate amount, and another working with 140 lbs., both engines exhausting at the same pressure. The economy was practically the same if judged by the absolute standard—the units of work produced per unit of heat. Why was the pressure not maintained at 35 lbs. per square inch instead of increasing it to the 140 lbs. per square inch? It was simply because there was a difference in the use of the steam, and in the steam distribution. To judge accurately of those two engines, he must know their possibilities in the conditions under which they were working. It was clear that an engine working at low pressure had not the same physical possibility of producing work economically as an engine at high pressure; he therefore thought something more was wanted than the absolute standard of efficiency. He admitted that for the purpose of calculating the amount of the coal bill the units of work per unit of heat were sufficient, and all it was necessary to aim at was to obtain an engine which would give the greatest number of work-units for the least number of heat-units. But engines had to be designed and built, and it had to be discovered how to make steam of a given pressure expanded to a given extent produce the greatest amount of work. It was when questions of that kind were considered that something more was required to be known than the absolute thermal efficiency. It was within certain limits practically immaterial, when dealing with efficiency considered in relation to the possibilities of pressure and expansion, whether the ideal engine was what a physicist might consider a perfect steam-engine or not. A datum line was required, and he had no doubt there would be a great deal of discussion on the question where that line should be drawn. The Clausius perfect steam-engine had a non-conducting cylinder. There were no steam-engines with a non-conducting cylinder, and as far as was known that standard was impossible of realisation. He questioned whether any of the standards that had been proposed could be considered as standards of a perfect steam-engine. All that could be done was to approximate to what might be considered a perfect steam-engine. He therefore thought that the Author had elaborated the question too highly. An indicator diagram with an expansion line $p\,v =$ constant provided a standard which, though not very different in result from that proposed by the Author, would be

Mr. Davey. very much simpler. He would assume the steam to be expanded to a terminal pressure of 1 lb. per square inch. To compare the efficiency of a condensing engine working under the condition of 100 lbs. per square inch pressure, its theoretical diagram would be a diagram with a small portion of the toe cut off. Enclosed within this figure was the actual engine diagram, and taking the mean pressure of this enclosed diagram and multiplying it by the number of expansions, supposing it to come to 20, and taking the mean pressure of the enclosing diagram multiplied into its number of expansions, and supposing it to come to 40, it was evident that the efficiency on this basis was 50 per cent. It was true this would show a different efficiency from that calculated in the way given by the Author, but he questioned whether it could be said that the ideal steam-engine the Author had prepared was much nearer the actual perfect engine than the engine indicated by the enclosing diagram. Three standards of comparison were adopted by the Author, the one with a small portion of the toe cut off, the absolute thermal efficiency, and also the one necessary to determine whether the engine being experimented with gave the best results in the conditions under which it was working, that was with the toe cut off to the point of release on the engine diagram. As he had said, that was a comparison which ought to be made by engine designers if they wished thoroughly to understand what their engines were doing and what they were capable of doing, supposing improvements to be possible.

Mr. Bryan Donkin. Mr. Bryan Donkin remarked the subject which the Author had so well brought before the Institution was a difficult one, and the members ought to be grateful to him for bringing it forward in such a graphic and interesting manner. The practical question of the best standard to use in comparing different engines was most important, and well worthy of full discussion. After discussion, however, it was one that might perhaps be better decided by a committee of scientific men. It could, of course, never be final, as any standard adopted by the Author or anyone else would have necessarily to advance with scientific progress and research. It was certainly very desirable that some uniform method, such as that before them, should be adopted and agreed upon by engineers, but such a standard should be as simple and as practical as possible to suit all motors. If a standard were adopted, it should not only be applicable to steam, but also to gas, air and oil, so that all classes of engines could be readily compared with steam, either saturated or superheated. That, he thought, was very important. The different standards of thermal

Mr. Bryan Donkin. efficiency of steam-engines proposed by the Author appeared to have many good points. From a thermodynamic point of view it would be necessary to base any standard upon the highest and lowest temperature limits for any motor working between them; but from a practical commercial standpoint there was much to be said in favour of giving the results of experiments in thermal units per brake HP. hour. On this point he agreed with Mr. Mair-Rumley that the latter standard was very practical, easy and correct; it was also much used in the United States. Thermal units were actually paid for in the shape of coal, oil or gas, and mill-owners cared less for the temperature limits than for their weekly coal- or gas-bills. In comparing lbs. of steam per B.HP. in steam-engines it was certainly not strictly correct, as mentioned in the Paper, to take the lbs. per B.HP. when the pressures of steam were not the same, especially when superheated steam was used. With regard to the interesting $\theta \phi$ diagrams, they formed to his mind a most elegant and useful method of delineating the amount of heat in an engine, and represented the quantities very clearly. He was glad to see that the Author had used them so much in the Paper. The $\theta \phi$ or entropy diagrams have rather a frightening effect upon engineers as a rule, but if it were remembered that the area between the water-line and the saturated line simply represented thermal units, he thought engineers would take to them more kindly.

Mr. Beaumont. Mr. W. WORBY BEAUMONT congratulated the Author upon having thrown over the old bogey, the mis-used Carnot function. He had stated why he objected to the use of the so-called Clausius ideal engine, and preferred to work out a diagram into which he imported what might be called a limitation. But it appeared to be questionable whether the Author was quite right when he said that engineers were in so little agreement as to what the standard should be. He thought it might be said that at least eight out of ten of any reports of experiments would show that engineers were using the standard that Mr. Mair-Rumley had mentioned. They had in that what he should call an ideal standard; not an imaginary one founded on a so-called ideal engine evolved in the study, but a standard which judged the steam-engine exactly as it would be judged whether a business was a paying one or whether it was not; that was, an engine had given to it so much heat, of which the engine had returned in work so many units converted into foot-pounds. As far as he could see, it was impossible to imagine a more truly ideal standard of efficiency, and it was an exceedingly simple one; it was,

however, only a standard for comparison. The Author was endeavouring to find a standard that would take into consideration some of the differences that must occur as a result of difference in temperatures, and in conditions of working. If it were possible to obtain a combination of standard of comparison, and of what might be called ideal efficiency, it would be worth a great deal. At the same time, as far as the thermal efficiency of engines was concerned, he admitted that up to the present the Clausius and other standards had not made it possible to predicate an economic improvement, it had not been found how to improve engines except from the results of seeing how much of the heat given to an engine was returned in the form of work. It was to the ingenuity and experience of designers and experimenters, guided by the main facts as to the difference between the heat supplied and the heat given out in the form of work, that all the great improvements were to be attributed, even including those brought out at the Thames Ditton Works, which had been the home of so many useful investigations, and amongst them those that had led up to the conclusions recorded in the Paper. Mr. Beaumont.

Mr. W. Schönheyder entirely agreed with Mr. Mair-Rumley that there ought to be only one standard of efficiency, and that the one he had mentioned was the right one. Without wishing to be considered frivolous or irrelevant he would ask whether it would be right to measure the height of a British soldier with an ordinary yard standard, and the height of a round-backed or knock-kneed soldier with a shorter standard? Or would it be reasonable to measure the work of an ordinary British sailor by ordinary foot-pounds, and the work of a lascar, with a different constitution, by a smaller measure? Again, if a steward to whom a cheque for £100 was given to buy a horse, wasted £80, and bought a horse for £20, would it be said that he had utilized 100 per cent. of the money entrusted to him? Obviously, he had only utilised 20 per cent. And the same thing applied to a steam-engine. Mr. Schönheyder.

Mr. E. Tremlett Carter remarked that, in presenting a standard of measurement of thermal efficiency based purely on the action of the steam-engine, the Author had separated the steam-engines from other heat-engines, and had introduced a method of arriving at a standard which was not directly applicable in the same way to gas-engines and explosion engines. He had also introduced an element of empiricism which must, at any rate from the logical point of view, destroy the scientific beauty of his standard. The clipping of the toe destroyed the figure, and a mutilated standard Mr. Tremlett Carter.

Mr. Tremlett Carter. was not strictly artistic. He could not see how the Author's method could be applied to a gas-engine, either to one exploding at constant volume or one exploding at constant pressure. Nor did he see how the method was to be applied to the important class of steam-engines of the rotary type—say a steam-turbine. The practical method which had been strongly supported by several speakers was an admirable one when dealing with practical tests. The ratio of the number of foot-pounds to the dynamical value of the heat supplied, always appeared a very small ratio—say 0·1 or under 0·2. Before it could be understood why 0·9 or 0·99, or unity, could not be obtained, a conception of some such standard as the Author had put forward was necessary. In other words, in order to understand the distinction between avoidable and unavoidable losses, some visualized standard, the Carnot, or the Clausius, or the clipped Clausius standard, if it might be so termed, was required.

Capt. Sankey. Captain SANKEY, in reply, observed that he had, in the Paper, referred to the method advocated by Mr. Mair-Rumley as the commercial criterion of engine economy, and from that point of view he agreed with Mr. Mair-Rumley. It was only the absolute thermal efficiency expressed in a form more intelligible to people who were not engineers. But the object of the standard of comparison advocated in the Paper was to have some means of ascertaining how nearly a particular engine approached what was possible taking account of the conditions under which it was working. The use of such a standard was exemplified in the experiments made by the late Mr. Willans, who had worked the same engine under different conditions of admission temperature and exhaust temperature, and calculated in each case how nearly the actual engine approached to perfection. In stating that the proposed standard of comparison did not take into consideration a rotary engine or a steam-turbine, Mr. Tremlett Carter was mistaken, because such a steam-engine could not give a greater return than the corresponding Clausius perfect engine; that was the absolute limit, no matter what might be the type of the engine. He had referred in the Paper to the use of what he had called the "type standard"; he did not know what this type standard would be for a steam-turbine, as he had not gone into the matter; but when worked out and compared with the Clausius cycle it would give the relation between the thermal efficiency of the turbine and of the Clausius cycle; and further, the comparison with the "type standard" of a reciprocating engine would give an idea of the thermal relation which steam-turbines

bore to reciprocating engines. It was thought by Mr. Davey that one thermal efficiency was insufficient, and so far he agreed with the Paper; but he proposed another standard of comparison, in which $p\,v$ = constant was the expansion line. Such an ideal engine had been considered in the Paper, and its $\theta\,\phi$ diagram was given in *Fig. 9*, and for reasons there discussed he thought that $p\,v$ = constant was not a suitable expansion line to take for a standard. Capt. Sankey.

Mr. DAVEY said he had in his mind a jacketed engine. He had proposed $p\,v$ = constant for ease of calculation, and because the error was not very great. Mr. Davey.

Captain SANKEY said for the type standard of a jacketed engine the saturation line should be taken as the expansion line, and not $p\,v$ = constant. The $p\,v$ = constant was proposed by Mr. Davey merely for simplicity in calculation. Certainly in this respect Mr. Davey's formula had the advantage of the formula given in the Paper, which was of considerable length, and was really worse than it appeared; it would have to be worked out by trial and error, which would be a long process, or by means of the $\theta\,\phi$ chart. But this difficulty was overcome at once by using a prepared set of curves, as shown in *Fig. 13*, from which the absolute thermal efficiency of the standard engine could be obtained by mere inspection when the limiting temperatures were given. Only a few curves were shown in the *Fig.* to illustrate the method; but if, in accordance with the President's suggestion, there should be an Institution standard established, these curves could be worked out in greater detail. After making a trial of an engine, it would be found that a certain number of heat-units were required per I.HP. per hour, and that gave the absolute thermal efficiency of the engine, and this divided by the absolute thermal efficiency of the standard engine gave the standard thermal efficiency. A numerical example was given in the Paper at p. 201. He thought this method was at least as simple as Mr. Davey's calculation, which required hyperbolic logarithms. It has also been remarked by Mr. Davey that the Clausius cycle necessitated a non-conducting cylinder, and there was no such thing in existence. Unfortunately, there was not; but the effect of a conducting cylinder might be taken account of in a "type standard." On the other hand, the loss occasioned by a conducting cylinder was one of the losses which the standard was appointed to try. He thought many engineers would agree that a portion of the toe should be cut off, but the question was how much. A standard that would include every kind of engine—steam, gas, oil, air, etc., was required by Mr. Donkin. But that was precisely Capt. Sankey.

Capt. Sankey. what absolute thermal efficiency did, as mentioned on the first page of the Paper. The standard thermal efficiency was useful for quite a different purpose, and the standard engine discussed in the Paper had reference only to steam-engines; but a gas-engine could be compared with its $\theta\ \phi$ diagram, as shown in *Fig. 1*, in an exactly similar manner, and the standard thermal efficiency of a gas-engine obtained. That there ought to be two thermal efficiencies, one to compare the absolute conversion into work by an engine, and the other to ascertain the degree of perfection under the conditions in which the engine was placed, Mr. Beaumont appeared to be in agreement with the Paper. He had laid on the Table a few copies of the $\theta\,\phi$ chart, which was a graphic representation of the properties of steam. This chart showed the temperatures, pressures, and volumes of saturated steam and also the volumes of 1 lb. of H_2O under various conditions (using that term to mean a mixture of steam and water); also the total heat expressed in British thermal units required to evaporate water at constant pressure from 32° F.

Correspondence.

Prof. Dwelshauvers-Dery. Professor V. DWELSHAUVERS-DERY remarked that the ideal steam-engine should have cylinder-walls absolutely impervious to heat; but its cycle would show the breaks due to the exhaust of the working fluid and its replacement in the boiler. There would thus be:—1st, admission at constant pressure p equal to that of the boiler, during which r thermal units per lb. of steam would be furnished, r being the latent heat of the lb. of steam; 2nd, adiabatic expansion prolonged until the pressure became equal to that of the condenser p' (or a higher one as proposed by the Author, but this would complicate the formulas), during which there was condensation, so that the dryness of the steam, which was unity, fell to a value x' which depended upon p'; 3rd, expulsion of the steam at constant pressure p', with consequent negative work taking place during the entire return stroke; 4th, restitution of the lb. of steam in the boiler and elevation of its temperature from that of saturation t', corresponding to p', to that of saturation t, corresponding to the initial pressure p. The quantity of heat expended in this operation was represented by $(q - q')$ thermal units per lb. of water, if by q be represented the heat of the lb. of saturated water at the temperature t, and by q' that of the lb. of water at the temperature t'. It would result that $q + r - q'$

thermal units would be expended per lb. of steam, or $\lambda - q'$ thermal units, where λ is the total heat of the lb. of saturated steam. Prof. Dwelshauvers-Dery.

The ratio of the heat equivalent of the work obtained to the total heat expended $(\lambda - q')$ represented the maximum efficiency of the real steam-engine, and its expression was very simple. The heat equivalent of the work done during admission was expressed by $A\,p\,u$. The heat equivalent of the work of the adiabatic expansion was equal to the difference between the internal heat of the lb. of the working fluid at the commencement and at the end of the expansion, or to $(q' + \rho) - (q' + x'\rho')$, where ρ was the internal latent heat of the lb. of saturated steam. If the notation u were employed in the same sense as above, the negative work for the expulsion of the steam was equivalent to $A\,p'\,u'\,x'$. Thus the calorific equivalent of the work was

$$A\,p\,u + q + \rho - q' - x'\,(\rho' + A\,p'\,u') = \lambda - q' - x'\,r'.$$

The efficiency was therefore given by the expression

$$\frac{\lambda - q' - x'\,r'}{\lambda - q'} = 1 - x'\,\frac{r'}{\lambda - q'}.$$

The value of u' was easily calculated by means of the adiabatic equation, by using steam Tables in which the entropy of the water and of the steam was calculated beforehand; ϕ being the entropy of the water and T the absolute temperature:—

$$\phi + \frac{r}{T} = \phi' + x'\,\frac{r'}{T'},$$

$$x' = \frac{\phi + \frac{r}{T} - \phi'}{\frac{r'}{T'}}.$$

The values of ϕ, ϕ', $\frac{r}{T}$, $\frac{r'}{T'}$, were found in the Tables opposite the pressures p and p' respectively.

Professor HEARSON remarked that the Author, after comparing the various proposed standards, had wisely rejected the ideally perfect engine of the Carnot cycle in favour of that of the Clausius cycle in which the feed-water was raised to the temperature of the boiler by heat provided from the source. He had not, however, given a sufficiently forcible reason for its rejection in saying that it required a dynamical feed-heater, and by merely adding that steam-engines were not so fitted. The advantages of compressing Prof. Hearson.

Prof. Hearson. the exhaust water and pumping it back to the boiler had been so much enlarged upon, that expectations had been raised that a not inconsiderable saving would result from this process. A few years ago most extravagant pretentions to a high rate of efficiency had been advanced in favour of the Marchant engine, in which a show of carrying out this compression was made, and the success of the pretention was largely due to the false hopes which had been created as to the economy which was due to the process. Those hopes still remained in the minds of many who desired to have a recognition of them in the adoption of the Carnot cycle for the standard engine. It was therefore important to show that those expectations were falsely grounded, and that there were good economic reasons why engines were not fitted with dynamical feed-heaters, and probably never would be.

The $\theta\phi$ diagram of the Carnot cycle, *Fig. 2*, page 190, showed that by expending an amount of mechanical energy, K, on the pumps which compressed the water from the exhaust-pressure and temperature to the pressure and temperature of evaporation, the expenditure of an amount of heat was avoided which was represented by M + K, a quantity actually expended in the Clausius cycle, *Fig. 2*, and in ordinary engines. The numerical value of the ratio $\frac{K}{M + K}$, or, the ratio of the heat utilized to the heat expended in this portion of the cycle, was 0·10 for 60 lbs. per square inch, and increased to 0·15 for 200 lbs. per square inch steam, the exhaust-pressure being taken at 4 lbs. per square inch in each case. Because these fractions were less than the efficiency-fractions of the corresponding ideal Carnot engines, heating the feed-water by the source of heat was condemned. But, if the process of pumping back the exhaust steam into the boiler were performed by an actual steam-engine, it would have to be done at the expense of some of the mechanical energy developed by that engine, the efficiency of which was much less than that of a Carnot ideal engine. Probably the highest actual duty which had ever been accomplished by the best devised pumping-engine had not exceeded a quantity equivalent to 7½ per cent. of the heat expended, and to obtain the equivalent of 5 per cent. was considered not a bad performance. The pumping of a mixture of steam and water under gradually increasing pressure and diminishing volume would probably be performed much less efficiently. Thus, if at the rates mentioned, mechanical energy was expended in saving heat, and the heat so saved was employed in working the pumps, there would be a dead loss of at least half the mechanical energy expended.

Without being further influenced in the same direction by considerations of the cost of the pumping machinery and its upkeep, the futility of this portion of the Carnot cycle was demonstrated. Prof. Hearson.

As to the relative merits of adopting for the expansion line the adiabatic curve, the saturation curve, or the $p v$ = constant curve, it might be observed that in ordinary engines, in which a very short space of time was taken for one stroke, the mass of the actual steam in the cylinder at the commencement of the expansion did really undergo adiabatic expansion, with the formation of a suspended mist, although contemporaneously a film of water was evaporated from the surface of the cylinder, producing a mixture, the resultant curve for which was approximately $p v$ = constant. The circumstances to which the initial condensation and re-evaporation were due, and which prevented the expansion from being adiabatic were undesirable. By superheating the steam, by steam-jacketing the cylinders, and by limiting the range of expansion in any one cylinder by using a series of cylinders, their wasteful influence was minimised. In order that the standard engine should be free from this blemish, the adiabatic curve must be adopted for the line of expansion. If either of the other curves were adopted, the falling off from perfection due to the conductivity of the metal of the cylinder would be condoned to a degree, the exact amount of which might not be realised.

With regard to the limits which should be adopted in estimating the efficiency of the standard engine, he thought that in these respects, as in the form of the expansion curve, no fault whatever in the design and construction of the engine apparatus should be condoned. An unimpeachable standard would then be provided. He would adopt, as the superior limit, the pressure and temperature of the steam in the boiler, and for the inferior limit the temperature in the condenser, or the temperature corresponding to the atmospheric pressure, in the case of a non-condensing engine. Having thus provided a standard, which was perfect within its limitations, it would be necessary to determine a scale of comparison in order that the relative efficiencies of two engines of different types, or in which the range of pressure and temperature was different, might be justly weighed, the scale being adjusted to give an advantage to an engine in which an attempt was made to utilize a large range, as compared with one in which the range was smaller.

Instead of arbitrarily assuming a terminal pressure in the standard engine, such as 0·15 of an atmosphere above the pressure corresponding to the exhaust temperature, as suggested in the

Prof. Hearson. Paper, it was probable that differences of opinion on this score could be more readily compromised by considering the adjustment which should be made for variety of range apart from the estimation of the standard itself. The adjustment could be effected by the addition of a bonus to the absolute efficiency of an engine, before ascertaining the relative efficiency. It would probably not be difficult for a representative Committee to agree to a tabulated scale of bonus to be added, whereby the performance of engines of different types could be justly compared. If the first apportionment should prove, on experience, to be not perfectly equitable, or the progress of engineering science should cause a modification to be desirable, the change could be made without tampering with the integrity of the standard engine. A comparison of the actual engine with the ideal standard engine would show the total shortcomings of the engine, and the tabulated bonus would express how much of that deficiency was, under the circumstances, excusable.

Prof. Jacobus. Professor D. S. JACOBUS, of Hoboken, New Jersey, considered it was ably shown in the Paper that the $\theta\ \phi$ diagram possessed great advantages in solving a certain class of problem, and in the present case by selecting the proper lines from the $\theta\phi$ chart, given in the Appendix, the theoretical efficiency of an engine could be determined much more readily than by constructing the $p\,v$ diagram and deriving the heat quantities by analytical means. The employment in an investigation of a "standard ideal engine," in which the expansion was carried to the point where the minimum friction was equal to the forward pressure measured on the combined diagram, appeared to be advisable. Doubtless the adoption of the efficiency of this standard ideal engine as a standard of comparison would do much to render engine tests more readily comparable. The number of heat-units per HP. hour, with the ratio of this quantity to the heat-units for the standard engine, supplied all the necessary data from a thermodynamic standpoint. He thought, however, that what the Author called a "type standard" also formed a valuable basis of comparison. In many cases the pressure at the end of expansion in the low-pressure cylinder was governed by the conditions under which the engine worked, as well as by the vacuum in the condenser. Thus, in the case of marine engines the terminal pressure could not be reduced below that at which the engine gave a sufficiently uniform rotative effort. Again, in direct-acting steam-pumps the conditions limited the ratio of expansion. It was desirable to show how nearly the distribution of steam, as shown by the indicator cards, approached the best theoretical distribution for the conditions under which

the engine worked, and a type-standard might be adopted to give this ratio. Prof. Jacobus.

The most useful measure of the efficiency of distribution from the standpoint of the steam-engine designer was obtained by comparing the area of the actual combined diagrams with that of a theoretical diagram, cutting off in the high-pressure cylinder at the same fraction of the stroke as in the actual engine, and following the law $p v =$ constant. A general practice in designing engines was to make use of such a simple theoretical diagram, and to multiply its area by a factor to allow for the difference which experience showed to exist between the theoretical and the actual areas of the combined cards for the class of engine under consideration. It was his custom to give this factor in reports of engine tests, and to plot the actual and theoretical diagrams on each other, so that the losses due to wire-drawing and condensation, or re-evaporation, were at once apparent. This factor, together with the percentage of water not accounted for at cut-off, measured the relative efficiency of engines of the same class.

Such a determination of the efficiency of distribution, together with the absolute thermal efficiency of the actual engine, and the comparison with the ideal engine, recommended by the Author, would give the most important data in an engine trial, and a uniform adoption of this method would greatly facilitate the comparison of different tests.

Mr. G. Luther, of Brunswick, observed that in all known forms of heat-motors, the heat developed by the fuel was not received, in accordance with the Carnot cycle, at the highest temperature, but while the temperature of the working fluid was rising. This theoretically incorrect reception of the heat was to be regarded as the chief reason why attempts at perfect conversion of the heat of the fuel into mechanical work had hitherto proved unsuccessful. Mr. Luther.

Mr. W. H. Northcott agreed with the Author in thinking that it was desirable to establish a common standard of reference wherewith actual results might be compared, and that two standards—an absolute one and a relative one—were necessary. In regard to both standards, however, there was room for considerable difference of opinion. The user of a steam-engine naturally thought mainly, if not wholly, of the cost of the useful work, taking into account not only the coal bill, but the first cost of machinery, the cost of labour and maintenance, and depreciation charges, &c. The only standard of efficiency from the commercial point of view was, therefore, that of the cost of the work done. The scientific investigator would no doubt advocate a standard based upon a Mr. Northcott.

Mr. Northcott. theoretical ideal, conceivable but impossible. The engine-maker would again express a preference for a standard with which his own engines might be most advantageously compared. Even in regard to the engine-factor itself there were difficulties, a point with which the Author had not dealt. Generally speaking, whether the absolute or the relative efficiency was obtained, and whatever might be the standard adopted, the brake HP., or its equivalent, should be employed, and not the indicated HP. Unfortunately, however, the former could not always be ascertained, and it was necessary to fall back upon the latter. This might introduce errors of considerable magnitude, owing to faults in the indicator cards, brought about by defects in the indicators themselves. With very high-speed engines indicator diagrams were extremely doubtful even when taken with care. As before the steam could do useful work it must drive the engine against its own frictional resistance, it appeared only reasonable that the steam should be credited with this work. The result, however, was the approximate dynamic efficiency of the steam—not of the steam-engine—and the efficiency was generally perhaps overstated. The internal engine friction no doubt diminished the cylinder condensation at the expense of the useful work. Under any circumstances the I.HP. might mislead, under some circumstances it might be quite delusive.

The useful mode of expressing engine efficiency employed largely in connection with pumping-engines was not mentioned by the Author. Here the efficiency was expressed in foot-lbs. of water raised per bushel or per pound of coal. An engine raising 1,000,000 foot-lbs. per pound of coal was doing good "duty," and with coal of standard quality assumed, this mode of expressing the engine efficiency was simple, serviceable, and instructive. It would be easy enough to separate the engine performance from the boiler performance, and the efficiency on any other basis could be deduced readily from the "duty." A duty of 1,000,000 foot-lbs. per pound of coal of 14,000 units represented an absolute efficiency of the whole apparatus of $\frac{1,000,000}{772 \times 14,000} = 0 \cdot 0925$, and an absolute engine efficiency of probably $\frac{1,000,000}{772 \times 10,000} = 0 \cdot 1295$. The Cornish efficiency showed exactly what the engine was doing, and in that respect had an advantage over an efficiency based either upon the Carnot cycle engine or any other ideal conception. The latter might be more scientific, but the usefulness of a rule often varied inversely with its scientific pretensions. The expression

of the results of a test in terms of heat expended for I.HP. hour, a method advocated by Mr. Mair-Rumley, was approved by the Author. This method was due to Rankine, and Mr. Northcott had himself published a series of comparative engine-results so expressed in 1876 or before. The heat expended per HP. hour might vary between 10,000 or 15,000 for first-rate engines, up to 100,000 for some of the no-flywheel pumping-engines. These figures were somewhat large for convenient comparison, and he would suggest expressing engine efficiencies in foot-lbs. of work per heat-unit expended. For a good engine the indicated work per unit of heat expended would be about 115 foot-lbs. for the entire process, or about 140 foot-lbs. per unit admitted to the cylinder. The Carnot cycle standard appeared to be at least as good as any. It was considered unsuitable by the Author because "the Carnot cycle was an ideal incapable of realization." But this was the case with every ideal. In this respect he saw little difference between the Carnot-cycle engine and the Rankine steam-engine of maximum efficiency. Both were practically unrealizable, and, moreover, the peculiar difference between the two standards might be removed by conceivable means. The nearer the standard was to the actual result the easier it would be to detect accidental and other errors, and this was the only advantage possessed by the Clausius standard over the Carnot-cycle standard. If the latter was rejected as unsuitable because unrealizable, it would logically follow that the best standard was the one nearest realization. This would, he thought, be the constant saturation standard used by Professor Osborne Reynolds and Mr. Davey. When an engine was furnished with a jacket to promote constant saturation, it did not appear unreasonable that its efficiency should be referred to a saturation standard. On the whole, however, the Carnot cycle standard appeared to be fairly unobjectionable. It was easily calculated, it applied to all types of heat-engines, it required fewer arbitrary assumptions than any other proposed ideal standard, and it was the most scientific. Mr. Northcott.

Professor C. H. PEABODY, of Boston, U.S.A., considered that the efficiency of the cycle advocated by the Author was the proper standard with which to compare the efficiency of the actual steam-engine, but that the efficiency of the Carnot cycle should be retained as the absolute standard. The primary reason why a steam-engine could not be made to work on the Carnot cycle was that no method had been devised to transfer heat to the working substance during isothermal expansion, and to withdraw heat during isothermal compression. The secondary reason, namely, that no Prof. Peabody.

Prof. Peabody. proper non-conducting material of which steam-engine cylinders could be made was available, affected both the Carnot cycle and the proposed standard cycle. It was not impossible that a material might be found which had as little effect on saturated steam as cast iron had on dry air, and which could be used for making or lining steam-engine cylinders. Such a material would allow a close approximation to adiabatic expansion and compression; the admission that such a material might exist was useful, as it gave a concrete conception of the problem under discussion. An engine with a cylinder of such material would correspond exactly with the requirements of the standard cycle, provided that it had valves and passages sufficient to avoid sensible loss of pressure. It would take steam at boiler-pressure, expand it adiabatically, exhaust against the back pressure, and give an adiabatic compression from the back pressure to the boiler-pressure. The exhaust steam could be condensed at the temperature corresponding to the back pressure and returned to the boiler. Each pound of the feed-water would be re-evaporated at the expense of $L_a + \theta_a - \theta_e$ thermal units, which quantity formed the denominator of the expression for the standard efficiency, and represented the heat supplied to the engine per lb. of steam. The numerator of the expression for efficiency represented the heat converted into work per lb. of steam. For the standard efficiency the work per lb. of steam was of course calculated by the aid of proper thermodynamic equations; for the actual engine the indicator-diagram furnished the basis for a like calculation. By such a conception of the problem attention was concentrated on the difference between the actual engine and what might be called the standard engine. That difference for slow engines of good design was due mainly to the energetic action of cast iron on saturated steam, and superheating, jacketing and compounding were so many devices for reducing that action.

In making the report of a thorough test on a steam-engine the efficiency of the Carnot cycle and of the standard cycle ought always to be given, together with the actual thermal efficiency and its ratios to the efficiencies just mentioned. The first ratio showed how far the engine fell short of perfection, and the second showed how near it came to its prototype. The standard back-pressure and the failure to expand down to the back-pressure formed subjects for experiment rather than for discussion. If a standard were agreed upon, probably sooner or later it would be proved by experiment that this standard was wrong, and then the standard itself became useless. The proper temperatures and pressures

from which to calculate the standard efficiency were the pressure near the cylinder in the steam-pipe, the terminal pressure in the low-pressure cylinder, and the pressure in the exhaust-pipe. Prof. Peabody.

It was convenient and customary to quote the number of pounds of steam per HP. hour, when stating the results of any steam-engine test; but it must be borne in mind that such a statement was inexact and might be misleading. The method of stating steam-engine performance in thermal units, on the contrary, was simple, exact, and scientific. It might be applied to engines using superheated steam, to engines with steam jackets, and to compound engines; further, it could be used for gas-engines and other heat-engines. If stated in terms of thermal units per HP. per minute the necessity of using large numbers or fractions was avoided. With proper Tables of the properties of saturated steam the calculations involved would be simple and expeditious.

As an illustration of the misconception that might arise from quoting lbs. of steam per HP. hour, he instanced two tests out of several series made on the experimental engine in the laboratory of the Massachusetts Institute of Technology.[1] This engine had three cylinders, 9 inches, 16 inches, and 24 inches diameter, with 30 inches stroke. With steam in the jackets of all three cylinders the engine used 13·7 lbs. of steam per HP.-hour, or 231·7 thermal units per HP. per minute. Without steam in the jackets it used 15·2 lbs. of steam, or 275 thermal units. The actual gain from the use of steam in the jackets was 15 per cent.; while the comparison of the lbs. of steam used indicated only 11 per cent. The efficiency for the test was $42{\cdot}42 \div 231{\cdot}7 = 0{\cdot}183$. The efficiency of an engine with a non-conducting cylinder working on the standard cycle would be 0·222; the efficiency for the Carnot cycle was 0·249. The ratios were:—

$$0{\cdot}183 : 0{\cdot}222 = 0{\cdot}82$$
$$0{\cdot}183 : 0{\cdot}249 = 0{\cdot}74.$$

The discrepancy between the actual and the standard efficiency was largely due to external radiation. A special test showed that 18·6 thermal units were radiated per HP per minute. If radiation could be suppressed, the engine would use 213·1 thermal units per HP. per minute, and would have an efficiency of 0·199, which was 90 per cent. of the standard efficiency, leaving only 10 per cent. to be attributed to condensation and evaporation.

---

[1] Transactions of the American Society of Mechanical Engineers, vols. xii., xiv. and xvi.

Prof. Peabody. The temperature-entropy diagrams showed clearly the nature and the effect of the various elements entering into the problem. Nothing could show more clearly the inadequacy of the other standards that had been proposed, and that were so thoroughly disposed of by the Author, whose diagram for finding the efficiency of the proposed standard cycle was admirable in its simplicity and directness. He could not, however, agree that the calculation of efficiency by proper equations was either difficult or laborious.

Mr. Porter. Mr. CHARLES T. PORTER, of New York, remarked that the questions presented on the trial of a steam-engine appeared to separate themselves naturally into three distinct classes. In order to derive the absolute efficiency, which constituted a class by itself, the engine was charged with the number of thermal units supplied to it, and was credited with the number converted into work. The ratio that the latter bore to the former expressed the value of the engine in the economic scale. On every test of a steam-engine, the primary object must be to ascertain these two amounts with the utmost attainable certainty. This having been done, three questions next presented themselves, and constituted the second class, as follows:—How did the ratio of the heat utilized compare with that in an ideal engine (or an engine reaching the highest ratio attainable), working within the same temperature limits, and with the same number of expansions? How did this ratio compare with those in other engines working under the same limiting conditions? and how did it compare with the ratios reached in engines working under different conditions of heat limits and expansions? All practical questions constituted a third class of two groups; what were the causes of the superiority or the inferiority shown? and by what means could a higher degree of efficiency be attained? Comparison with a standard engine did not appear practical for two reasons:—general agreement was not possible upon the standard engine, and advances in engine performance would probably compel frequent renewal of the standard. These advances might be expected to result from a more distinct realization of the fact, that, in engines working merely saturated steam, the heat for conversion into work was obtained chiefly or wholly (depending on the character of the expansion curve) from steam that was not represented on the diagram. He considered the engine quite distinct from the boiler, as it seemed important that the performance of each should be separately ascertained.

Mr. Schröter. Mr. M. SCHRÖTER, of Munich, agreed with the Author as to the necessity of having a universally adopted standard, so that all

figures of thermal efficiency would be directly comparable; but he did not think it urgent to substitute the (so-called) Clausius standard as adopted by the late Mr. Willans. In each class of heat-engine, the cycle of the ideally perfect engine would be to some extent arbitrary, depending on what losses were considered as inherent in the nature of the engine, and those ideally avoidable. Upon two points there was general agreement; namely, that when the temperatures of admission and exhaust were given, the ideal of absolute perfection was the Carnot process; and further, that the omission of the dynamical feed-heater was an unavoidable loss. As regards all other losses, the determination of how far they were avoidable was open to discussion. A standard of comparison ought not to be affected by arbitrary numbers such as that chosen by the Author for the limit of expansion. From the thermo-dynamic point of view it was clear that the available heat would be best utilized by carrying the expansion as far as the back-pressure corresponding to the temperature at which heat was abstracted from the working fluid, and it seemed that the mechanical perfection of the engine was better left out of consideration, the more so as the Author's proposed standard involved calculations of considerable length and complication, and this would be a hindrance to its general introduction. Moreover, if the Clausius-Willans standard were adopted, then some ideal process could be employed for the cold-vapour engines of the compression system, the inversion of the steam-engine (refrigerating engines with ammonia or carbonic acid as a working fluid). With these the suppression of the expansion cylinder might be regarded as an unavoidable loss, just as in the case of the steam-engine, the omission of the dynamical feed-heater was so regarded, and thus the reversibility of the thermo-dynamical process found expression in the choice of the standard heat and cold-engine. This was of so much importance in theory that it was worth the little sacrifice which must be made from the more practical point of view, in considering that the theoretically best terminal-pressure of the expansion was identical with the back-pressure. Mr. Schröter.

Professor ROBERT H. SMITH, wished, with reference to the Author's definition of "standard efficiency" to protest against the common phrase "heat converted into work." Heat was energy; work was not energy, and could not be converted into heat-energy or *vice versâ*. Work was the process of transfer of energy from one mass to another, or of transformation of energy from one form to another form within one mass. He would prefer to confine the use of the word "work" to the transfer only of energy from mass to mass, Prof. Smith.

Prof. Smith. and not to transformation. But when the latent (or potential) energy of heat-elasticity of, say, a gas, produced rapid outflow of the gas from the containing vessel, it was so invariably the custom to say that mechanical work had been done in producing the kinetic energy of the outflow that it seemed for the present desirable to include transformations within the meaning of the term "work." It could be said quite properly that heat was spent in doing work. An arbitrary selection was made by the Author of a very few of the many physical and economic conditions which affected steam-engine efficiency, and all other operative conditions were thrown so much into the shade as to make them unworthy of consideration in determining the character of the "ideal" engine, seemingly because they were merely "practical," in spite of their being influential to the extent of reducing "actual" efficiency from 100 per cent. to 50 per cent.

The calculation of the complete thermo-dynamic efficiency necessarily included the actions of furnace, feed-pump, boiler, engine, condenser, and air-pump. It might be very convenient and perfectly scientific to split this whole efficiency into separate factors, one of which, for instance, would deal with the action of the engine alone; but each such separate factor had no reference to any complete thermo-dynamic cycle. Even including the whole of the thermo-dynamic apparatus, it was well known that the cycle of operations was never "complete." The air-pump never delivered the discharge from a surface-condenser at the temperature of the feed. With an injection-condenser the condensed steam was brought more nearly to the primal condition of the feed; but still not wholly so, and in both cases a considerable amount of the working fluid was discharged in the form of low-pressure steam. In non-condensing engines the bulk of it was discharged in this form, mixed with only a small volume of water in the form of cloud. It ought to be recognised that these thermo-dynamic operations were essentially and necessarily "incomplete," that was to say, not represented by a "complete cycle"; and that they involved waste thermo-dynamic quantities beyond what was usually termed the "waste" or "discharge" heat.

He could find no justification for assuming the Carnot cycle, or the "isothermal-adiabatic," or "two-temperature two-entropy" cycle, as the ideally perfect one; or that the aim of engine-makers ought to be to approximate as closely as possible to the Carnot cycle. The consideration of the Carnot cycle had been of immense importance in the elucidation of the true laws of thermo-dynamics and in helping towards a true conception of

thermo-dynamic efficiency, but no evidence had been produced that even Carnot himself ever considered this cycle to have any great further importance. If the efficiency of thermo-dynamic engines were limited by considerations of temperature alone, then no doubt the Carnot cycle, which gave the maximum possible efficiency under the sole condition of prescribed temperature limits, would be of supreme importance, and it would then be the endeavour of all engine-makers and users to approximate as closely as possible to it. But pressure-limits were of equal, if not greater, importance because of considerations of strength and stiffness. Volume limits, that was limiting grades of expansion, were of very essential importance because the increasing bulk per HP. of the motor machinery accompanying greater expansion not only increased the weight and therefore the prime cost of the material spent in building the engine, but increased also the prime cost in machining, and the general costs of maintenance; and, moreover, increasing expansion decreased the mechanical efficiency by diminishing the uniformity of the driving effort. This last, at any rate, reached a maximum with one certain grade of expansion depending on the speed and rate of reciprocation of the parts, beyond which further expansion would not be desirable if mechanical efficiency alone were to be considered. Calculations of the best ratio of expansion based on a comparison of the cost of increasing bulk with the saving in steam and fuel, had often been made, and this particular item influenced the design of steam-engines to a greater extent than was generally appreciated. The most economical exhaust-pressure appeared hitherto to have received little attention; perhaps because if a condenser was to be used at all, the extra cost for making it and the air-pump larger and more efficient was small compared with the greater advantage obtained in steam-consumption. But even here the same considerations of cost were practically operative in determining limits. Thus, for instance, the extra cost of reducing the back-pressure from 3 lbs. per square inch absolute to 2 lbs. or $1\frac{1}{2}$ lb. per square inch was not generally found to be justified by the advantage gained, this extra cost being very greatly more than was involved in reducing it from say 7 lbs. to 6 lbs. or $5\frac{1}{2}$ lbs. per square inch. Prof. Smith.

Temperature limits operated in two ways. First, high steam-temperature involved correspondingly great chimney-waste of heat (although this extra waste was perhaps not serious as compared with the increased steam-efficiency), and also slower conduction of heat through the boiler heating surface. The slower conduction was accompanied by decreased boiler horse-power.

Prof. Smith. Secondly, the keeping of working surfaces in good condition became rapidly more difficult and costly as the steam-temperature rose above certain limits related to the evaporative qualities of the lubricants used.

Admitting the fundamental importance of the Carnot cycle reasoning for the theoretical purpose of establishing primary thermo-dynamic laws, it should not be forgotten that this reasoning has absolutely no direct bearing upon practical problems, because it had involved infinitely slow conduction of heat to and from the working substance, and therefore zero HP. In fact, the Carnot process could not be carried out consistently with the development of any HP. at all in the boiler and engine. This did not mean that an isothermal-adiabatic indicator diagram necessarily meant zero HP. The reasoning, whereby Carnot did so much towards establishing correct scientific thermo-dynamic principles, did not lie in the use of this particular kind of indicator diagram, but depended on the use of "infinitely small" conductive differences or falls of temperature, involving "infinitely" slow rates of conduction. Such conditions of working were infinitely remote from those of any possible practical process.

If the upper and lower pressure limits were alone of importance in restricting the working of a pressure thermo-dynamic engine, then to obtain maximum thermo-dynamic efficiency the whole of the conductive heat-supply ought to be at the upper limit of permissible pressure, and the exhaust of the working fluid ought to take place wholly at the lowest permissible pressure. If temperature limits were alone operative, the whole supply of heat should be at the highest temperature allowed, and the whole exhaust of heat at the lowest allowed. If both temperature and pressure limits be imposed, then the maximum efficiency possible under the given conditions would be obtained if the conductive heat-supply were given at the upper limit of permissible pressure until the upper limit of temperature was reached and continued at this upper limit of temperature (with falling pressure) until the whole heat allowed per lb. of steam had been so supplied.

In either case, after the supply of the heat allowed per lb. had been finished, adiabatic expansion should be continued (in order to obtain maximum efficiency) until the limiting volume imposed by conditions other than those of thermal efficiency had been reached. Temperature limits probably received more consideration than pressure limits—first, because in the thermo-dynamic theory of an "elementary engine" the mathematical expression for the thermal efficiency took a simpler form when given in terms of

temperature than in other terms, and secondly, because so long as the evaporation of water into steam was alone considered, the isothermal line was coincident with the isobaric line and the identity had prevented engineers recognising the impracticability of working along an isothermal *per se*. But now that the advantages of superheating steam were being more generally recognised, it was never attempted to superheat along an isothermal. The invariable method was to superheat along an isobaric, maintaining the same pressure as that used for evaporation. It was true that Rankine many years ago set forth the advantages obtainable from superheating by wire-drawing at the throttle-valve and the slide-valve ports; but this method was only tolerated in so far as it was found practically unavoidable. The general rule for the mode of conducting heat so as to obtain the highest thermo-dynamic efficiency was to select that method which, among those permitted by other necessary limiting conditions, increased by the largest additional amount the latent (or potential) elastic energy of the working substance. Prof. Smith.

Professor R. H. Thurston was greatly interested in the subject of the Paper, and had already given it very close consideration.[1] He had endeavoured to ascertain what process could be practically applied to realize with exactness the idea of Rankine, who sought to identify that ratio of expansion at which the steam-engine would give the required amount of power at minimum annual total running cost, inclusive of interest, &c. That method, when applied to current practice, proved a failure in consequence, as he had discovered, of the fact that the influence of the extra thermo-dynamic wastes of the machine were not taken into account. The later attempts to follow Rankine's methods were fatally invalidated, both by this neglect and, even more seriously, by the fact that these who sought to apply the system to modern forms of engines, apparently without suspecting a vital difference between the two cases, endeavouring to ascertain what adjustment of the expansion-gear would correspond to the requirement of securing the highest possible return from a stated engine already constructed and in operation. The results were found, in many cases, to be contradictory of experience, and widely erroneous solutions of Rankine's, "the designer's," problem. Other problems, which he had been accustomed to call the "Owner's problems," were: (*a*) To ascertain what, with an engine of given dimensions, would be the Prof. Thurston.

[1] "The Several Efficiencies of the Steam-Engine," Transactions of the American Society of Mechanical Engineers, 1882; Journal of the Franklin Institute, 1882; "Manual of the Steam-Engine," vol. i. chap. vii.

Prof. Thurston. best ratio of expansion, and what the best amount of power to be delivered, highest financial returns being demanded. (*b*) The adjustment of cut-off and power at which a limit would be found in the securing of satisfactory profit. These were entirely distinct forms of the problem from those which confronted the designer seeking to properly proportion an engine for a stated amount of power, and then led, if correctly solved, to radically different solutions, giving results which would be absurd as solutions of the designer's problem.

He saw no objection to using as the standard the absolute efficiency. He would obtain the ratio of the heat transformed, and usefully applied, to the total quantity of heat furnished the engine, in the unit of time, measuring both in the same way, either in thermal or dynamic units, in either calories or foot-pounds, and would take this efficiency as the recorded measure of value of the machine as a thermo-dynamic apparatus. Measured by this standard, one engine had an efficiency, in a correct sense, of 5 per cent.; another gave 20 per cent., as did actually the Milwaukee steam-pumping engine, which was, at the time of its formal trial, the most remarkable engine, in this respect, probably, in the world.[1]

The engine-cycle of highest efficiency, and of absolutely defined value, and which should therefore serve as a standard, both for these reasons, and because it was the perfect limit toward which all work of the engineer was expected to constantly approximate, although never by any possibility to fully attain, was, of course, the Carnot cycle. This seemed the more suitable from the fact that it was a form of cycle which, thermal wastes aside, could be produced in the actual engine, and he had devised a number of methods of securing such adjustments of mechanisms as would, in an engine composed of non-conducting substances, actually give such a cycle. In this case, with complete adiabatic expansion and compression, the maximum possible efficiency of heat-conversion was attained. The comparison of the efficiency of any actual engine with the efficiency of the corresponding Carnot cycle afforded an absolutely accurate and scientifically exact means of securing a measure of the value of the former.

Still another standard, frequently adopted in America in place of either of the above, which he was accustomed to place beside the others, was the Rankine cycle, which differed from the Carnot cycle in the fact that no clearance or compression was assumed,

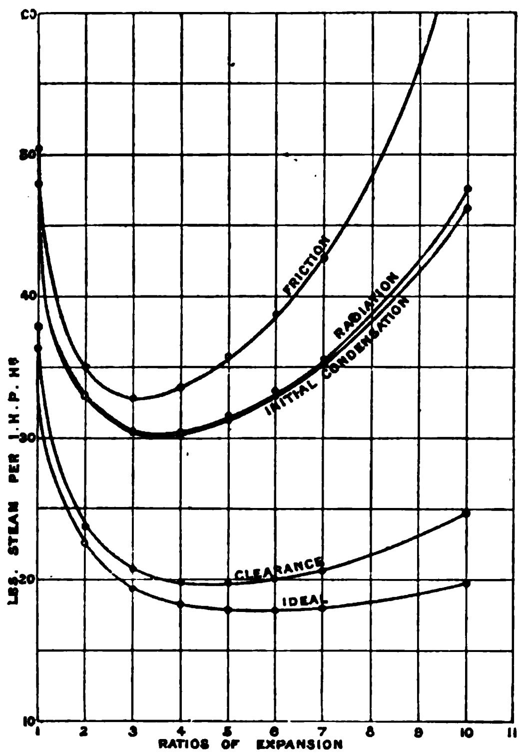
---

[1] "Maximum Contemporary Economy of the Steam-Engine," Transactions of the American Society of Mechanical Engineers, vol. xv. No. dlxxii., p. 313.

and also in terminating the expansion-line at the same point with the actual engine under comparison. Prof. Thurston.

The selection of a standard thus became easy; it depended simply upon the purpose sought to be accomplished by the engineer. If the aim was to ascertain what part of the work-equivalent of the energy supplied was utilized, in any case, then an unapproachable ideal of unit efficiency became properly and

Fig. 21.

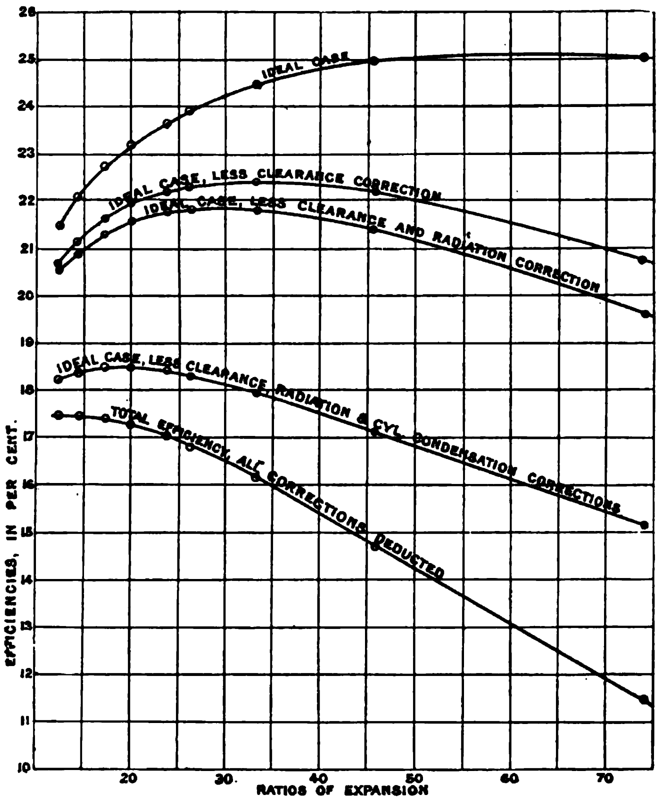


naturally the standard. If the desire was to ascertain how nearly the engine tested approached an ideal, conceivable but, however closely approachable, never actually attainable, the proper and natural standard to be taken for the case was the Carnot cycle. If, finally, the purpose was to show how closely a certain engine approached the ideal engine of Rankine, one free from all extra thermo-dynamic wastes, and having a similar steam-distribution to that of the actual case, then the efficiency of the Rankine cycle

Prof. Thurston. was taken as the only proper and natural standard. He saw no reason why, for these several purposes, each of these standards should not be strictly defined for use in the particular case, each which it best suited; precisely as the mile, the yard, the foot, or the inch were used as standards of measure.

The employment of such a variety of standards, even in the same

Fig. 22.



work, was often desirable and justifiable, and he had frequently placed such a series in a report to meet the requirements of various readers.[1]

As a standard with which to compare the outcome of the numerous tests of all kinds reported by the engineer for miscellaneous purposes, he inclined to the adoption of the Carnot cycle; but he saw no reason why the absolute efficiency should

[1] Transactions of the American Society of Mechanical Engineers, vol. xv. p. 338.

not constitute the ultimate reference. The Author's proposed standard of comparison was, in fact, the Carnot cycle, with a conventional displacement of the back-pressure line, and with the introduction of the Rankine idea, no clearance and no compression. He, however, preferred the Carnot or the Rankine, unmodified but precisely defined as to limits. There would seem to be, however, no serious objection to the statement, where it proved for any reasons desirable, of a series of efficiencies, measured against appropriate standards. The restriction to a minimum necessary number, and those of the highest and simplest forms was, nevertheless, most desirable. All measured efficiencies should ultimately give the measure of energy required in heat supplied, rather than in weight of steam, where both were not given. Prof. Thurston.

In the graphical representation of the quantities which determined useful and wasteful expenditures and ideal or real efficiencies, he had for many years been accustomed to employ a system illustrated in *Fig. 21*, which showed the variation of useful and wasted energies of a common Corliss mill-engine of about 200 rated HP., and of 18 inches diameter, and 42 inches stroke of piston, making 85 revolutions per minute, with 100 lbs. per square inch steam-pressure. The economy of the machine was here gauged by the amount of steam consumed, and the various items of total expenditure were given in superposed curves; the magnitude of the ordinate intercepted between each and the next lower curve measuring that particular item indicated in the legend on the curve referred to. The expenditures of a well-known pumping-engine of high efficiency, made up on an absolute efficiency-scale, were shown in *Fig. 22*. The pistons were 18 inches, 32 inches, and 48 inches diameter, with a stroke of 36 inches; it was rated at a capacity of 5,000,000 foot-lbs. in twenty-four hours, and a duty was guaranteed by its builders of 120,000,000 foot-lbs. per 1,000 lbs. of steam supplied from the boilers. Its actual performance was a duty of 128,108,123, foot-lbs. on 100 lbs. of dry coal, for a period of nine months. The diagrams showed clearly the manner in which its various wastes varied with varying conditions of operation as computed by securing from an actual trial, the constants for use in well-established formulas for wastes, and the exact formulas of thermo-dynamics so far as regarded the ideal case.

He esteemed it a privilege to express his appreciation of the elaborate and interesting work of the Author, and to compliment him on the skill with which he had employed a system of graphical illustration, the uses of which could not yet be confidently foretold. It was now many years since Professor J. Willard Gibbs

Prof. Thurston. in his first Paper, detailed the nature of this thermo-dynamic diagram. To Mr. MacFarlane Gray and the Author was due the distinction of having accomplished much in its adaptation to the discussion of important problems of the steam-engine.

Mr. Wilkinson. Mr. H. D. WILKINSON asked whether the Author's statement, that an engine working with saturated steam returned a greater percentage of the heat-units in effective work than one working with superheated steam, was to be applied generally, or whether he had in mind a particular case of an engine working under some limited conditions.

Capt. Sankey. Captain SANKEY, in reply to the Correspondence, was glad to observe that so many of the correspondents expressed themselves clearly on the advantage there would be in establishing a recognised standard of comparison for thermal efficiency, but pointed out that there was wide disagreement amongst them as to what this standard should be. For instance, Professor Smith remarked (p. 234), "He could find no justification for assuming the 'Carnot' cycle . . . . as the ideally perfect one; or that the aim of engine-makers ought to be to approximate as closely as possible to the Carnot cycle;" whereas Professor Thurston took the opposite view and stated (p. 238), "The engine cycle of highest efficiency . . . . the perfect limit toward which all work of the engineer was expected to constantly approximate . . . . was, of course, the Carnot cycle." A number of arrangements devised by Professor Thurston would, in an engine composed of non-conducting substances, actually give a Carnot cycle; but Professor Smith remarked (p. 236) that "the Carnot process could not be carried out consistently with the development of any HP. at all in the boiler and engine." Many other points were raised in the correspondence to which he would liked to have replied, and there were also many suggestions in respect of the standard of comparison to which he would have referred had he not thought it best to refrain from doing so, seeing that the whole question was now under discussion by a Committee appointed by the Institution; doubtless the various suggestions would be considered by the Committee. He was obliged to Mr. Wilkinson for his question, because he believed there had been some misunderstanding as to his statement at p. 206. That statement has reference only to the standards of comparison when supplied with the same number of heat-units per lb., as was again pointed out at p. 214. It did not follow that an actual engine, using saturated steam, utilized a greater proportion of the heat supplied to it than an engine using superheated steam. As a matter of fact, owing to cylinder condensation, the latter utilized a greater amount than the former.

---

31 March, 1896.

SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., President, in the Chair.

(*Paper No. 2927.*)

"The Tampico Harbour Works, Mexico."

By ELMER LAWRENCE CORTHELL, D.Sc., M. Inst. C.E.

TAMPICO is situated near the mouth of the River Pánuco, about mid-way between the port of Vera Cruz and the mouth of the Rio Grande, which divides the United States from Mexico. A large part of Mexico is table-land, between 7,000 and 8,000 feet above the level of the sea, the lowlands, or "tierra caliente," along the Gulf of Mexico and along the Pacific being quite narrow. The descent from the table-land to the lowlands is abrupt, and necessitates heavy gradients on the railroads; the Mexican Railway to Vera Cruz has a maximum gradient of 4 per cent. The main line of the Mexican Central Railway, extending from El Paso to the City of Mexico, bisects this great table-land, its general course running parallel to the Pacific coast. In 1883, a branch line to tide-water at Tampico was begun from a point on the main line near Aguas Calientes, a distance of about 406 miles.

On behalf of the Mexican Government, a survey and plans for the improvement of the channel over the bar at the mouth of the River Pánuco were made in 1881, by the late Mr. James B. Eads. When the railway to Tampico was nearly completed, the harbour improvements had to be undertaken. On the 30th August 1888, a contract was made with the Mexican Government for these improvements; and in June and July 1889, the preliminary surveys were made by the Author on behalf of the Mexican Central Railway Company. On the 20th August, a report and plans were submitted, and were subsequently approved by the Company and by the Mexican Government. The contract for the works was made on the 6th February 1890, and operations on the ground began on the 18th March. Between the 15th and 19th April, the commencement of the works and the opening of traffic on the Tampico division of

the railway were inaugurated by General Carlos Pacheco, the Minister of Public Works of the Republic. The works were completed by the end of 1892, and have already greatly increased the commerce of the port, raising it from one of little importance to rank probably as the second in the Republic.

The River Pánuco, which flows into the Gulf of Mexico at Tampico, is one of the largest in Mexico. Its watershed lies in parts of eight states of the Republic; and its tributaries extend many miles west of San Luis Potosi, on the Mexican National Railway, and southward to the valley of Mexico. The entire drainage of that valley, on the completion of the drainage channel and tunnel through the mountains, will flow into the Tula River, one of the tributaries of the Pánuco. The area of the watershed is about 36,000 square miles, extending from 19° to 24° N. lat. The rainfall upon this watershed is very variable; sometimes many months, and often one or two years elapse with but little being recorded. Near Tampico, and between it and the base of the mountains, the annual rainfall is about 40 inches; but, as is usual in tropical countries, there are occasionally very heavy local rainfalls, and at times a general rainfall over nearly the whole watershed, which produces in the river at Tampico a large volume more or less charged with sedimentary matters. The effect of such conditions was either to retard for long periods the development of the channel, or to discharge from the jetties into the sea during construction so great an amount of sediment as to form a temporary deposit immediately in front of the works. After the jetties were completed, there occurred during 1892 an exceptional drought, even for this watershed, there being almost no rain except in the immediate vicinity of the works during the year. Inquiries were made in regard to the rainfall upon various parts of the watershed; and it was ascertained that the insignificant floods, of short duration, which reached the mouth of the river, came from the immediate region, and that in several of the largest tributaries, such as the Rio Verde, Santa Maria, Moctezuma, Amejaca, Tula, etc., which drain about three-quarters of the watershed, and ordinarily furnish a large volume to the Pánuco, no floods occurred during that year. From gaugings of the river during one of the greatest floods, in July 1893, the discharge was found to be somewhat over 150,000 cubic feet per second.

The river between Tampico and the sea, Fig. 1, Plate 4, a distance of about 7 miles, has, at mean flood stage, a cross-section of about 25,000 square feet, and a slope of about 7 inches in a mile. Its average width is about $\frac{1}{4}$ mile for many miles above

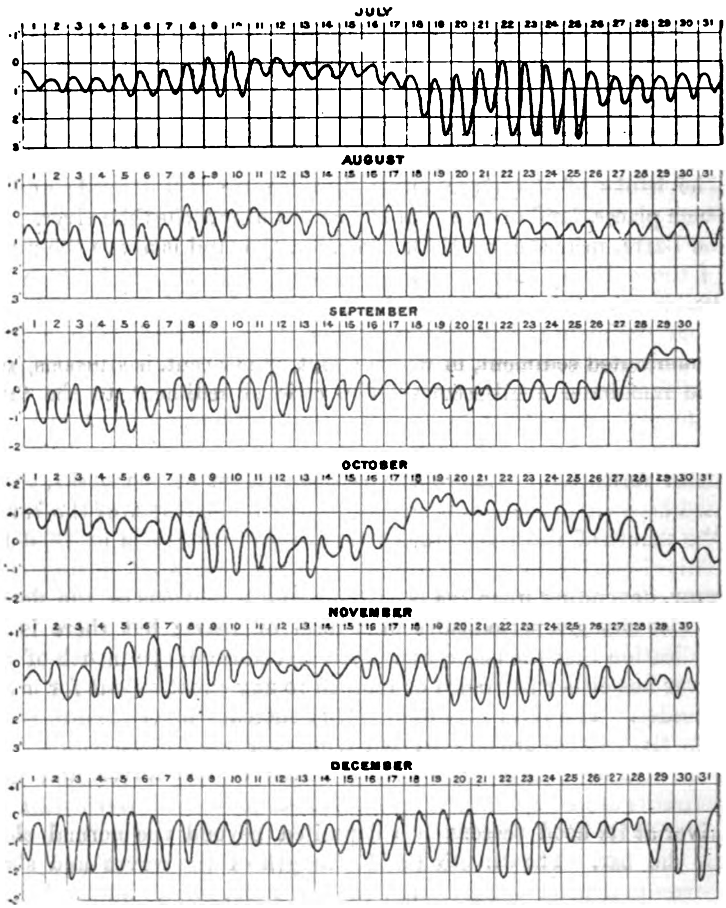
Tampico; and the adjacent shallow lagoons of large area, to which it is connected at several points, form a tidal reservoir of considerable size, aiding somewhat at low stages of the river in maintaining the channel at the mouth of the river.

The tides in the Gulf of Mexico, into which the river flows, are diurnal, and have an average range of about 15 inches. The continuous tidal records, *Figs.* 2, by an automatic tide-gauge, show that there is at times a much greater range of tide than the average, 2 feet or 2 feet 6 inches being often recorded. This greater fluctuation occurs at sufficiently short intervals to materially assist in maintaining the channel at the mouth of the river. The banks of the river below Tampico are well defined; and in some places, land of considerable height approaches the river. At La Barra, near the mouth of the river, the land is above the reach of the ordinary tides and river-floods, and is firm and stable for buildings. When the level of the river is low, the water is free from sediment; but during floods it is charged with a fine, comminuted sediment, of which about 18 per cent. is siliceous, and the remainder argillaceous. The ratio of sediment to the total volume is approximately by bulk $\frac{1}{1300}$, and by weight $\frac{1}{750}$.

The river discharges into the gulf in one stream, there being no delta formation. Before the commencement of the works, there had been little change in the position of the sea-slope of the bar at the mouth of the river since the survey of Mr. Eads in 1880–81. This slope, however, changes its position somewhat during each year, depending upon the occurrence and conditions of the floods. It also changes periodically in a term of years; but there is no indication that the shore-line north and south of the mouth of the river has either advanced or receded to any great extent for many decades. The river may temporarily encroach upon the gulf when the river forces are active; but whenever they become quiescent, the abraiding and transporting forces of the waves and gulf currents are incessantly at work removing the material which the river at its flood seasons has deposited beyond the normal slope of the bar. The direction and strength of the waves and shore currents depend largely upon the direction, force, and persistence of the wind. At this point, the winds prevailing during the season of low water in the river are from the north and north-east, and are severe and persistent, causing the wave currents to sweep southwards along the coast. During the summer months, when the floods occur, the south-east trade-winds prevail; but they are usually not strong. When there are no winds, a true littoral current, the gulf-stream current, is formed, flowing into the

Gulf of Mexico, round the promontory of Yucatan, and hugging the shore through the Gulf of Campeche, past Vera Cruz to some point north of Tampico. At this place it leaves the shore

Figs. 2.



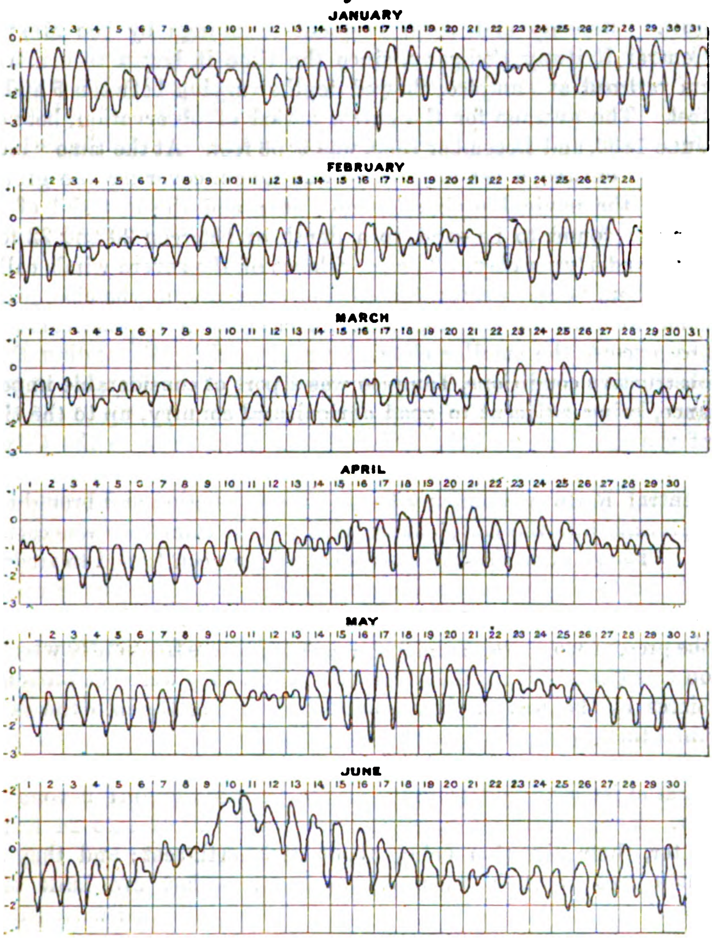
AUTOMATIC TIDE-GAUGE RECORD AT THE MOUTH OF THE RIVER PÁNUCO, 1ST JULY TO 31ST DECEMBER 1892.

Zero—Average flood-tide level of Gulf of Mexico.

for about 100 miles, and then pours with a strong current out of the gulf into the ocean round the southern coast of Florida, at the Florida Straits. From operations at the mouth of the River

Mississippi, it has been found that this gulf-stream current is sufficiently strong in the gulf, a great distance from the land, to cause a reflex current, producing a littoral current flowing westward.[1]

Figs. 2.



AUTOMATIC TIDE-GAUGE RECORD AT THE MOUTH OF THE RIVER PÁNUCO,
1ST JANUARY TO 30TH JUNE 1893.

Zero—Average flood-tide level of Gulf of Mexico.

The position and height of the bar at the mouth of the Pánuco,

---

[1] "A History of the Jetties at the Mouth of the Mississippi River," by E. L. Corthell, pp. 232, 234.

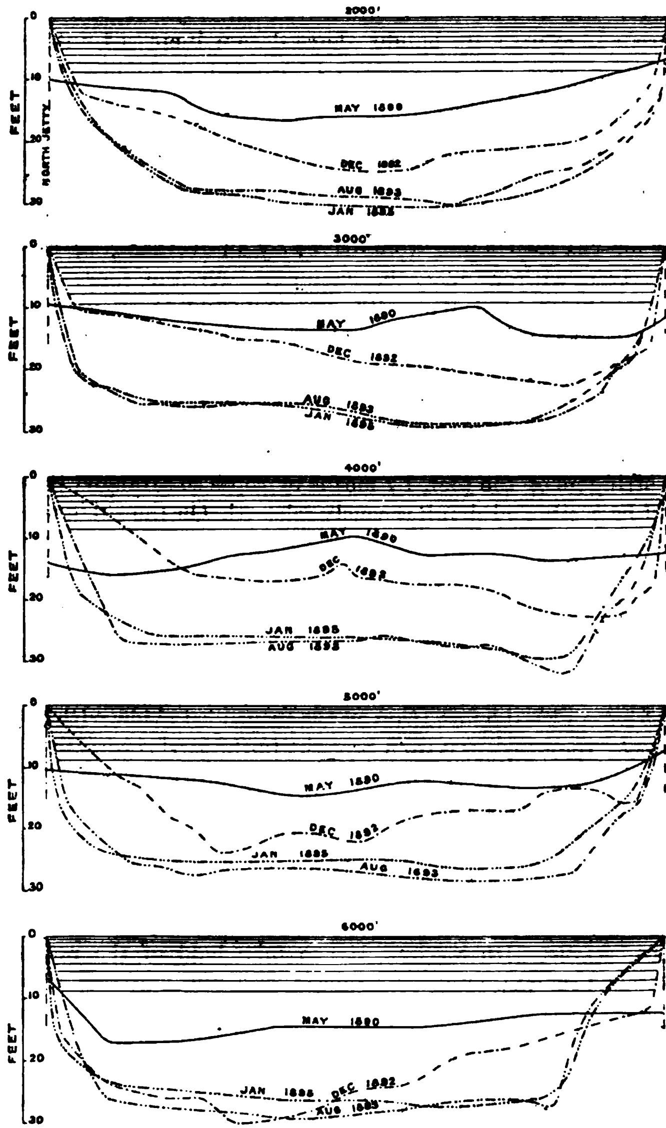
caused by the river floods, were changeable before the works were begun. About seven years prior to the commencement of the works, the mouth of the river was almost completely blocked by the formation of an island, appropriately named "block island," round which the river passed through a tortuous channel into the gulf. Monthly and more frequent soundings by the Mexican Central Railway Company, since the time it began to construct its railroad at Tampico, showed depths varying between 5 and 12 feet. The average for the entire period of observation, between June 1883, and December 1889, was 9·06 feet. At the time "block island" existed, a set of borings was taken, covering the ground where the navigable channel now lies; and the material of the bar was found to be sand, to a depth of between 20 and 22 feet, with underlying clay. The prevalence of the severe winds called "northers" during several months of the year, and the changeable conditions of the bar, rendered its navigation impracticable for any except the smaller class of vessels. Notwithstanding these obstructive conditions, Tampico was a port of considerable importance, being adjacent to good agricultural country, up to the time of the completion of the railway from Vera Cruz to the City of Mexico about thirty years ago. From that time till the Mexican Central Railway Company began its construction and brought its materials into the port, comparatively little commerce was carried on. The smaller class of vessels have been accustomed to trade at this port since Americus Vespucius made his first landing on the American Continent in 1497. From that date to the time when the present works were undertaken, vessels were frequently wrecked on this changeable and dangerous bar. If they were not broken to pieces by the waves, they would gradually settle into the sands until they became entirely submerged.

The improvements have been effected by the construction of two parallel jetties, built from the shore-line into the gulf beyond the bar. They are about 6,700 feet long, and extend into 24 feet of water, their direction being about east-north-east; and they are 1,000 feet apart between centre lines. They are built of a hearting of brush mattresses, sunk and consolidated with rubble stone. At the time the works were begun, the railway terminated at Tampico, Fig. 1, Plate 4; but it was decided to extend it to the mouth of the river, in order that it might be used not only to transport materials, brush, stone, etc., to the works, but also to carry that material out as the work progressed. For this purpose, a trestle pier, Fig. 3, Plate 4, was constructed. At the shoreline, it was 8 feet in the clear to the under-sides of the caps above

"mean high-tide," which was used as datum for the construction, and for the depths which are given in *Figs. 4.* As the pier proceeded seaward, its height above datum increased until at the ends it was 12 feet above it. It carried a double line with occasional cross-overs, to allow the passage of trains in both directions, facilitating rapid construction. It was used not only for transporting brush, stone, and material for the work itself, but for constructing the mattresses, which were suspended from it in the space between the under-side of the caps and the water. The piles for the trestle pier were driven by an overhanging balanced pile-driver with a 4,000-lb. hammer. As the pier extended towards the sea end, its width was increased to 60 feet to hold up the suspended mattresses, which at that point were 84 feet wide athwart the jetty line.

For building the matresses, supports of pine scantling, about 3 inches by 8 inches, and of a length equal to the width of the mattress, were suspended athwart the jetty line from the caps and stringers of the pier, by means of ropes so arranged that they could be easily and simultaneously released. On the skids were laid other lines of scantling, 3 inches by 6 inches, for about 60 feet, the length of the mattress lying longitudinally with the jetty. In these scantlings, forming the bottom framework of the jetties, there were inserted before being laid on the skids, iron rods $\frac{3}{8}$ inch in diameter, and of the length required for the thickness of the mattress, which ranged between 4 feet to 7 feet. These longitudinal strips were placed 5 feet apart on the suspended skids, with the rods upright; the brush was then brought to the work, either in a barge alongside when the sea was smooth, or by cars overhead if the sea was rough. It was packed as closely as possible, first in a layer athwart the jetty, and then in a layer lengthwise with the jetty, and so on until the required thickness was obtained. Mattress strips, or scantlings, of the width of the mattress, were then placed over these rods; and by means of heavy mallets and powerful "grip" levers, with an iron jaw to take hold of the rod, a pull of 3,000 lbs. was brought to bear, and the mattress was compressed about 20 per cent. The rods were then bent down over the strips to hold them securely. Between six and twelve waggon-loads of rip-rap stone, each car carrying about 12 cubic yards, were then usually hauled by the locomotive to the point over the mattress. The ropes suspending the mattress were then released, and the stone from the waggons thrown on to it, causing it to sink out of sight in a few moments. Mattress work was thus carried on when it would have been impossible to do so with a

Figs. 4.



TAMPICO HARBOUR WORKS.—COMPARATIVE CROSS-SECTIONS BETWEEN JETTIES.

NOTE.—The numbers above the five *Figs.* indicate the distances from the shore-end of the jetties at which each set of sections was taken.

floating equipment. By this method of construction, which, with some change in details, was followed throughout the work, the mattresses were built round the piles, of which there were between four and eight in each bent, the bents being 15 feet apart. The only modification was in the varying thickness and width of the mattresses, and in often substituting ½-inch rods for the smaller rods in the corners or outer sides. Only one or two of the mattresses were injured by the waves.

In order to avoid widening the trestle-pier for the purpose of suspending wide mattresses, the caps were extended by 8-inch or 10-inch square "outriggers," or extension pieces, temporarily attached to the top of the cap by iron yokes, so that after the mattress was dropped the outriggers could be moved forward to new positions. The outside ropes for suspending the mattresses were held from the ends of these outriggers. On a work subsequently carried out at San Diego, California, the loss of the supports on which the mattress was carried has been avoided by what are called "trip-planks," of sufficient size and in sufficient number to support the mattress. The mattress is dropped by releasing one end of these trip-planks, which then either swing outboard entirely free of the mattress, or are pulled up through the mattress as it falls, by a line attached securely to the rounded end.

The brush used on the work was obtained, either from the immediate banks of the river, in which case it was brought down by barges and unloaded from them directly upon the work, when the sea was calm, or from near the railway, when it was brought to the work upon waggons, which were provided by high side-stakes to carry a large amount of brush. The character of the brush was not satisfactory; it was generally crooked and very stiff, and did not yield to compression during construction, or give way to form solid work until it had been heavily loaded a long time with stone under water. For this reason, the final compression after loading was nearly 50 per cent. of the bulk of the mattress on completion. This fact made the cost of the mattress work, as finally consolidated, nearly as great as that of the stonework.

The piles of the trestle-work under the rails were generally of creosoted pine, and, with the other timber, were imported from United States ports, no suitable timber for such work being found near the works. The amount of creosote in the piles was 12 lbs. per cubic foot, which was found to be sufficient, as it was only necessary to preserve them during the construction of the work, or

about three years, for the *teredo navalis* is found in all parts of the Gulf of Mexico. At some localities, ordinary untreated pine timber will last only one or two years. At the mouths of rivers bearing sediment, the ravages of the *teredo* are not so marked and severe as at other places. A recent examination of the mattress work in the jetties at Tampico shows that the sedimentary matters in the water have almost entirely preserved it from the *teredo*.

The position of the mattress work in the jetties as consolidated, on account of the compression caused by the great load of stone upon it, cannot now be ascertained. In Fig. 5, Plate 4, are shown sections of the north jetty at points 1,000 feet, 4,000 feet, and 6,600 feet from the shore end; and in Figs. 6, sections of the south jetty at points 2,000 feet, 5,000 feet, and 6,700 feet from the shore end. During construction, the mattresses were arranged in tiers, diminishing in width towards the surface of the water; and they were brought to the surface before being consolidated by the final load of stone. The amount of stone required to sink and hold mattresses on such works cannot be determined by previous experience, unless the conditions are nearly the same, as illustrated by the following examples:—

	Cubic Yard.
Mouth of Mississippi, rock used for sinking and holding mattresses per cubic yard of brushwood	0·075
Tampico, North Jetty, per cubic yard of brushwood	0·440
Tampico, South Jetty, " " "	0·290

These great differences arise from the fact that, at the mouth of the Mississippi, on account of sustained floods and the continuing deposit of sediment, the mattresses were almost immediately filled with this sediment, and consequently required less rock to hold them in position; and further, along nearly two-thirds of the length of the jetty, there was little exposure to waves. The north jetty at Tampico was much exposed to the waves, with very little sediment in the river water to assist in holding down the mattresses. On the south jetty, the work was largely protected by the north jetty, and by a sand-bar which filled in rapidly behind the south jetty out to a point about 4,500 feet from the shore.

As the south jetty was on the opposite side of the river from the railway terminus, it was necessary to ferry the waggons of rock and brushwood across it. This was done by a "model" barge, with two tracks holding six waggons, aprons being arranged, adjustable to the tide, at the end of a short pier on each side of the river. A locomotive for hauling the waggons on the south side was ferried over and used between the barges and the work.

The sidings and other necessaries for a small terminus were arranged on that side of the river. On the north side, or terminus of the railway, an extensive yard was laid out. Considerable room was needed, for the reason that, during the prosecution of the work, as many as seven trains of thirteen waggons of rock were brought to the work every night, and set upon the sidings for the shunting locomotive of the works to deal with on the following day. Ordinary American flat waggons were used, about 36 feet long between couplings, and capable of carrying a load of about 15 tons.

The total number of waggons of rock, brought to the works during construction, was about 36,500, carrying about 10 cubic yards of rock each. At the beginning of the work, the new formation of the railway on the division between Tampico and the rock quarry was in bad condition, unsuitable for such heavy rock traffic. In order to raise the track, over 10,000 waggon-loads of sand, from the sand dunes at La Barra, were brought by the returning empty waggons. After an examination of the various sources of rock, it was decided to open a quarry at a point called El Abra, 78 miles from the work, where there was a rock bluff about 100 feet high near the railroad, with sufficient room for sidings. The rock is limestone, not suitable for dimension work, but producing very good rubble of any size. Its weight is between 162 and 172 lbs. per cubic foot, which is nearly the weight of ordinary granite. Another quarry was opened on one of the tributaries of the Pánuco, from which about 9,000 cubic yards of rock were obtained of an inferior quality, and weighing only about 145 lbs. per cubic foot. The total amount of brushwood used on the jetties until the 31st of December 1892, the close of the construction work, was 390,532 cubic yards, of rock 373,048 cubic yards, of untreated pine piling 196,087 lineal feet, and of creosoted pine piling 57,260 lineal feet; the total amount of pine timber being 2,018,950 feet, board measure.

It became evident as the work progressed, that, on account of the waves, it would be necessary to consolidate the exposed north jetty with a large quantity of rock, and by flat slopes, as well as the sea end of the south jetty, which, from the direction of the waves, was also exposed. There being no suitable sand for concrete within a convenient distance, and probably none within several hundred miles along the line of the railway, the Author, in 1891, examined several harbour works in Europe for the purpose of ascertaining the conditions where similar work had been built and maintained with rubble stone. He examined the jetties at the mouth of the Maas at the Hook of Holland, which had been main-

tained for fifteen years at a yearly cost of not more than £646 1*s*. 10*d*. These jetties are about the same length as those at Tampico, and are built of almost the same class of material, but are exposed to waves of much greater force and to greater tides, the works being covered twice daily. This successful maintenance has been due largely to the construction of a crown with easy slopes, offering the least possible obstruction to the waves, and to the stones being laid in such a way as not to be disturbed by the waves. This method was subsequently adopted at Tampico, as far as it was possible to utilize it with the very rough and irregular rock available. The rock was laid and adjusted in proper position above low tide by means of four or five derricks working on the trestle overhead.

The costs of the materials used in the works are shown in the following Table:—

	£	s.	d.	
Piles from the United States	0	1	4½	per lineal foot.
Palma or other approved native pile	0	0	11	"

These prices do not include creosoting.

	£	s.	d.	
Creosoted piles from the United States	0	2	5½	per lineal foot.
Mattress work	0	6	2	per cubic yard.
Brush "	0	4	7½	"
Large stone	0	9	3	"
Small "	0	7	5½	"
Concrete blocks	2	1	8	"

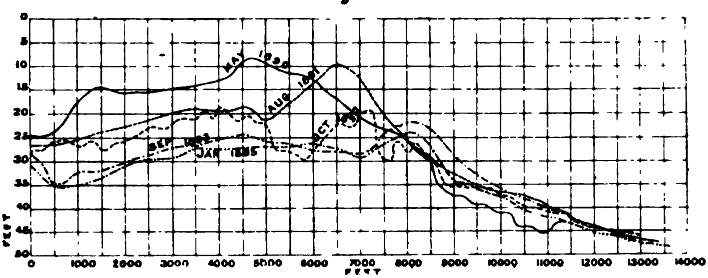
For conversion into English money, $4·86 = £1.

The prices included, not only the materials named, but also all iron, straps, fastenings, ties, scantling, framework, etc., required for their use. In the specifications, the stone was described as being either "small stone" or "large stone," the former not exceeding ½ cubic yard in size, and the latter including all larger stone not exceeding 3 cubic yards. The brush and native piles were to be used largely on lines of "inner jetties," the object being to make a depositing ground for sand and other materials washed over the jetties by the waves, and thus to prevent this material from encroaching upon the channel. During the progress of the work it was found unnecessary to build these jetties, which were to be placed a short distance inside of the main jetties. On account of the great compression of the mattresses, a much larger amount of stone was required than originally expected; and this largely increased the cost of haulage, and added to the total cost of the work. The final estimate to the contractor, made on the 1st of January 1893, was £293,989 16*s*. 10*d*. There were

many large expenses connected with the works in addition to the contractor's payments (general, incidental, engineering, management, etc.). The railway company charged the harbour company at the usual rates for hauling materials, as well as for materials furnished from its stock in warehouses and shops, the transportation of the contractor's labourers, and a percentage of the general expenses of the railway company. The total cost of construction and maintenance of all the works to December 1894, was £617,543 6*s.* 5½*d.*

The progressive development of the channel, both in depth and width, resulting from the works, is shown in the comparative longitudinal profiles of the channel, *Fig. 7,* and by the sheet of comparative cross-sections of the channel between the jetties, *Figs. 4.* A comparison of Figs. 8 and 9, Plate 4, shows that the shore-

Fig. 7.

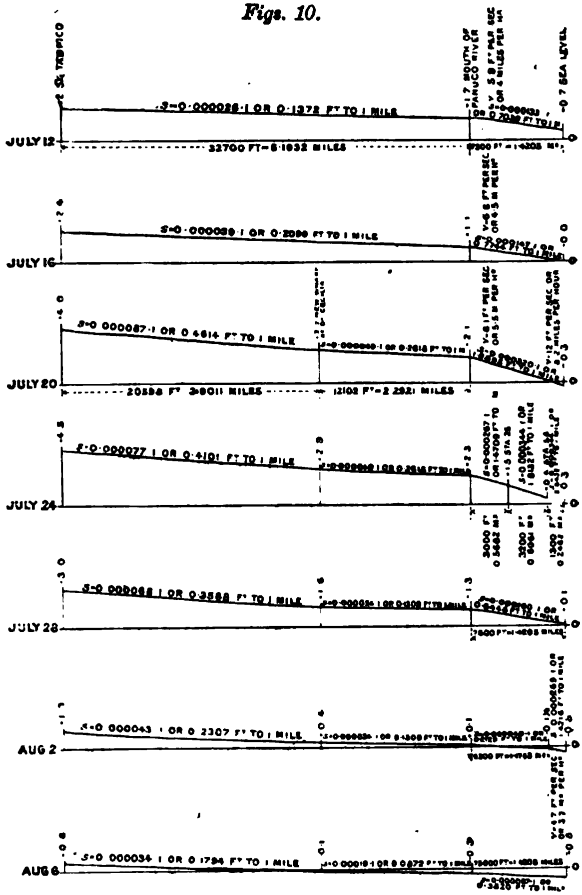


COMPARATIVE LONGITUDINAL SECTIONS BETWEEN JETTIES SHOWING DEPTHS IN CHANNEL.

line seaward of the jetties has advanced by reef formation about 1,500 feet on the north, and 3,600 feet on the south. The results concurrent with the construction of the works and the development of the channel are similar to those which occurred at the Mississippi jetties and on other works of a similar character. The abnormal discharge of a large amount of material excavated from the channel, in addition to the normal amount of sedimentary matters in the river floods, deposited during construction a larger quantity of sediment immediately in front of the jetties than could be immediately disposed of by the action of the waves and currents in the gulf, causing a temporary shoaling at that point, and a temporary advance of the bar immediately in front of the works. A comparative profile of the bar at different stages of the works at the Mississippi jetties is similar in its appearance to that shown in *Fig. 7.* It may be expected, now that the channel is fully

developed, and no more heavy materials are to be thrown out from it into the gulf, that the abraiding effect of the waves and currents in the gulf will continue, and that the mouth of the channel will be kept clear of deposits.

Figs. 10.

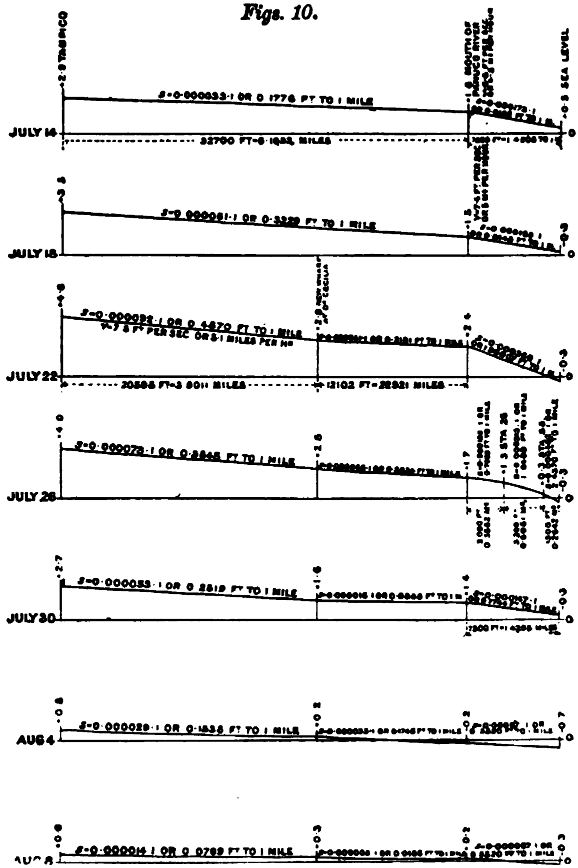


SURFACE SLOPES OF PÁNUCO RIVER AND JETTY CHANNEL DURING FLOOD OF JULY–AUGUST 1893.

Prior to the construction of the jetties, the river and tidal water discharging at the mouth of the river spread out fan-like over the submerged bar. The effect of the construction of the jetties, compared with the processes of nature, was almost instantaneous. The river had no time to adapt itself to this sudden

change in the conditions. The jetties therefore, and the bar which they crossed, prevented the normal flow of the flood waters into the gulf, until the channel through the bar became deepened by the action of the current. The jetties and the bar formed

Figs. 10.



SURFACE SLOPES OF PÁNUCO RIVER AND JETTY CHANNEL DURING FLOOD OF JULY–AUGUST 1893.

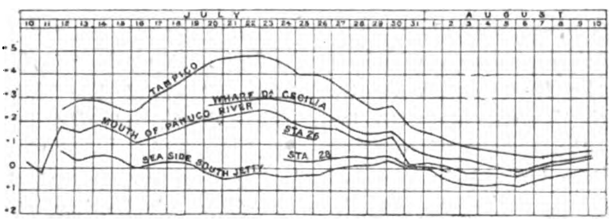
a dam which obstructed the flow, and backed up the waters of the river in times of flood as far as the City of Tampico, and probably considerably further up-stream. During one of the floods in 1892, the river at Tampico was raised 2 feet above the level which would have been reached by a similar flood before

the jetties were built. In addition to these general conditions, which might exist at all works of a similar nature, an obdurate inner bar existed between points 3,200 feet and 4,000 feet from the shore, caused largely, and perhaps wholly, by the numerous wrecks. No indications of these wrecks were found in the borings that had been made in a previous year. As this part of the channel developed, and the depth increased to about 17 feet, steamers began to use the channel. One of them was injured by a piece of metal protruding from the bed of the channel. Examination by a diver disclosed several wrecks, and a large amount of heavy detached material, scattered over the bar. In one of the wrecks was found a number of boilers, which had evidently been consigned to the Port. Shafting of great size and weight was found, and had to be dragged ashore. Strata of conglomerate rock, several inches in thickness, consisting of cement-like material, seem also to have been formed by these wrecks; and around them had grown a shell formation separated by isolated coral formations. By the use of dynamite, however, most of these materials were removed after several months of expensive and difficult work. The hydraulic dredger, which had been brought for the purpose of loosening the bar and removing the material to the sea, pumped up into its tanks a large number of silver dollars. It is recorded that a vessel, loaded with 60,000 Mexican dollars, endeavouring to run the blockade of the United States vessels during the war of 1848, was wrecked on this bar.

This inner bar not only caused an abnormal elevation of the river floods behind it, but also prevented the deepening of the outer bar at the end of the jetties. In July 1893, an unusual flood occurred, due to heavy rainfall over the entire watershed. This flood continued for about twenty-two days, during which time the inner bar was entirely removed; and whatever remained of the wrecks was dissipated or sunk below the bed of the river to a depth that will not interfere with the future navigation, as after the flood, a depth of 27 feet was found, an increase of 10 feet. Observations were taken during this flood upon the slopes of the river in various portions of the jetty channel, particularly between the end of the jetties and the level of the gulf outside, especially during the ebb-tide. The reason for making the latter observation was, that a steamer, capable of going at least 12 miles an hour, was unable, after several attempts during the height of the flood, to enter the channel. In *Figs. 10* are shown the slopes noted at different stages of that flood, between Tampico and the end of the jetties. The maximum slope at the end of the

jetties between July 20 and 26, during the height of the flood, was more than $2\frac{3}{4}$ feet per mile; and the velocity was 8·2 miles per hour. In *Fig. 11* are shown the ebb-tide curves at the different gauge stations during this flood. With such slopes and velocities, the channel rapidly deepened; and a large amount of material was excavated by the strong current and carried into the gulf. The total amount of suspended sediment discharged at the end of the jetties was 7,518,518 cubic yards, the total amount scoured out of the channel between the jetties and discharged into the sea being 1,201,985 cubic yards. The calculations for ascertaining the amount of material scoured out were made from cross-sections taken, at every 200 feet, from the charts of surveys made before and after the flood. The results showed a nearly equal amount scoured out in each 200 feet between station 0 and

Fig. 11.



SIMULTANEOUS EBB-TIDE CURVES AT DIFFERENT GAUGES DURING THE FLOOD OF THE PÁNUCO RIVER OF JULY–AUGUST 1893.

station 66, except that a greater scour took place between stations 24 and 48, comprising the length of the "inner bar."

STATISTICS OF THE FLOODS OF JULY AND AUGUST 1893.

Ratio of sediment to water, by bulk . .	0·000767
" " by weight .	0·001345
Discharge of river at top of flood . . .	153,063 cubic feet per second.
Total discharge during flood equal to that of twenty days at a maximum stage .	261,493,000,000 cubic feet, or 16,520,233,000,000 lbs.
Total discharge of sediment during flood .	203,000,000 cubic feet, or 22,188,000,000 lbs.
Material scoured out of channel between jetties	32,432,000 cubic feet, or 23,892,000,000 lbs.
Total amount of material carried into gulf during flood	235,432,000 cubic feet, or 26,080,000,000 lbs.

The cross-sections taken immediately after this flood, *Figs. 4,*

show that the channel was deep and wide from the beginning to the end of the jetties. All obstructions were removed, and the sides became uniform over the entire length. The channel, however, has continued to improve. The depth of the channel over the "outer bar," directly in front of the jetties in the gulf, in August, immediately after the flood, was about 19 feet; and it increased to about 21½ feet at the end of the month, after the deposit of sediment had ceased and the tidal action had had an opportunity to take effect. From that date, until March 1895, the depth on the outer bar varied between about 20½ and 22½ feet; but on the 28th of March, a survey showed a clear 24-foot channel between the river and the gulf, which was maintained until August 1895. Comparison of the chart of the survey of 1890, Fig. 8, Plate 4, before the works were begun, and that of January 1895, Fig. 9, Plate 4, shows the remarkable changes in the bar. In 1890 an immense bar existed with a minimum depth of 9 feet, and with a width of 3,000 feet between the inside and outside 12-foot curves. In 1895 there existed through this entire bar a channel 24 feet deep with an average width of 680 feet at that depth. In May 1890, the least depth in the cross-section at the shore end of the jetties was about 27 feet. This depth actually decreased during the construction of the works. This was natural, as the jetties formed, in connection with the bar, a partial dam, raising the water surface behind them, slackening the current and inducing deposit of sediment. This action continued until the summer of 1893, at which time the inner bar was entirely removed, and the outer bar nearly so. In December 1892, there were only 25·7 feet on this portion; and the river bed was shoaling over the whole distance to Tampico. The opening of the channel through the bar in the summer of 1893 caused not only this section, but the river for some distance above, to be considerably deepened. By the survey of August 1893 the depth on this section was found to be about 33 feet; and from that date until August 1895, the entire river, for a considerable distance above the jetties, continued to deepen, having attained a depth of about 38½ feet; and the 30-foot channel has been carried more than 2,000 feet into the jetty channel from the river. Probably this action, both above and below the shore end of the jetties, will continue to increase until a greater section exists than the original section of May 1890, over the entire distance between the jetties and Tampico. Surveys made since August 1895, inside and outside the jetties, show that very satisfactory changes have taken place. The channel near the sea end of the jetties has

widened and deepened; but the most noteworthy change has been the wearing away of the shoals that had formed in the sea on the extended line of the south jetty. This heavy shoal has been almost entirely swept away since August 1895; and there only remains a small conical-shaped shoal at a considerable distance from the end of the jetties, and south of the line of the channel. Tracing the progress of this change, the first effect was the widening of the deep channel just north of the sea end of the north jetty to nearly twice the width that existed in August 1895; then, in connection with this change, the formation of a deep trough extending entirely across the width of the jetty channel, and southward for a considerable distance, cutting the shoal in two. These strong currents athwart the ends of the jetties then attacked the remaining part of the shoal outside, and had nearly obliterated it in December; and probably if a survey were now made, the very small residue of the shoal would be found to have entirely disappeared. According to the daily records of depths in the jetty channel, a navigable channel, with a minimum depth of 25·3 feet inside the jetties, and 27·3 feet at the end of the jetties, was developed about the middle of December 1895, and continued without any diminution of depth up to the 1st February 1896.

Before the construction of the works, commerce was conducted under great difficulties. No sea-going vessels could enter to discharge or load cargoes. It was always necessary to use lighters, which had to be towed at least 10 miles from Tampico to the vessels at anchor off the mouth of the river in the Gulf. When the weather was tempestuous, it often happened that a vessel would lie a month or longer waiting to be discharged. Steamers were frequently obliged, after lying-to for hours or days, to proceed to another port. Vessels of the largest class trading in the Gulf of Mexico can now enter and leave at any time without delay. In addition to the wharves at Tampico, the Mexican Central Railway Company has built a wharf, 600 feet long, about one-third of the distance from the jetties to Tampico; and a coal-wharf, 600 feet long, is in process of construction near the present wharf, Fig. 1, Plate 4. The Waters Pierce Oil Company has built a wharf a short distance above the Mexican Central Railway wharf; and the Tampico Terminal Company has a wharf, 400 feet long, a short distance above the latter. The Montery and Mexican Gulf Railway has a wharf still further up the river, 553 feet long; and above that point a small lumber dock has been built. Nearly the entire distance between the jetties and Tampico, on both sides of the river, may be utilized for piers and docks whenever the

commercial conditions require it. The river is wide enough at all points for the largest steamers to manœuvre with safety and ease. The changes in commercial conditions have greatly reduced the cost of dealing with freight. On merchandise freight, the saving is about 12*s.* 4*d.* per ton. The value of the saving in time to vessels, on coal and lumber vessels, averages more than £205 15*s.* per vessel. The following Table shows the increase in the amount of commerce since the jetty channel was opened.

Year.	Tonnage of Imports.	Tonnage of Exports.	Mexico City, Value of Exports.	Year.	Tonnage of Imports.	Tonnage of Exports.	Mexico City, Value of Exports.
			$				$
1885	9,672	7,603	733,591·29	1890	21,188	8,074	910,738·54
1886	10,824	10,696	916,407·09	1891	22,582	8,853	1,100,966·92
1887	9,731	11,878	760,769·76	1892	80,670	28,702	5,910,300·63
1888	13,817	7,893	635,460·80	1893	115,813	54,117	10,015,145·35
1889	11,671	7,462	684,653·27	1894	143,306	48,780	13,465,830·00 (£2,770,746 18*s.*)

The value of imports in the first six months of 1895 was $1,009,481·18, as against $558,112·58 in the corresponding period of 1894. The total number of vessels entering the port of Tampico has increased from 48 in 1885, to 328 in 1894.

The entire work was under the direction of the Author as Chief Engineer, the Resident Engineer being Mr. Arthur F. Wrotnowski.

The Paper is accompanied by twelve tracings and five photographs, from which Plate 4 and the *Figs.* in the text have been prepared.

Discussion.

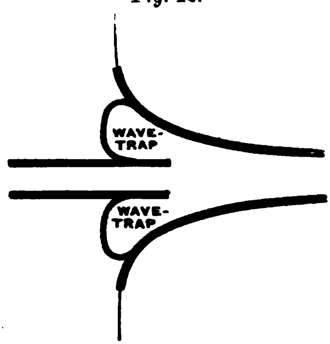
Sir Benjamin Baker.

Sir BENJAMIN BAKER, K.C.M.G., President, said the Author was personally known to many members of the Institution as an American engineer of great ability and energy. He was the right-hand man of Mr. Eads in the construction of the Mississippi jetties, works similar in character to those which were the subject of the Paper, but on a larger scale. That was a splendid school for any engineer to be brought up in, for Mr. Eads was a striking example of that remarkable type—the old-fashioned American engineer. He was not trained as an engineer, but he carried out the St. Louis bridge, which still remained the most remarkable arched steel bridge in the world; and, having completed that, he turned his attention to the Mississippi jetties, securing the Author as his resident engineer. At that time, there was no certainty that works of that character would prove successful under the given conditions; and it seemed a very bold thing for a self-made bridge-engineer to take a firm stand against the authority of all the United States Government hydraulic engineers, and to say that it would be a success. He well remembered Mr. Eads coming to him twenty or thirty years ago, on returning from a visit to the mouths of the Danube with Sir Charles Hartley, and telling him that on seeing at a distance the ball showing the depth of water on the bar, or in other words the practical realization of the theories which had been so contested in the States, he could not speak because of the great lump in his throat. The Author carried out the Mississippi jetties under Mr. Eads; and then, following the same plan, he succeeded in bringing the work described in the Paper to a successful conclusion. There were points of difference between the two works which were very instructive. The mattress work, for example, which was so largely used in the Mississippi, was effectual to a greater degree there than in the case of the Tampico harbour works, because of the remarkable silting up in the Mississippi. At the mouths of the Mississippi, the climate was very bad; but it was far better than the climate at the Isthmus of Tehuantepec, where the Author had carried out the railway; and it was not to be wondered at, under those circumstances, that his health had suffered much in the execution of his duty. He was sure the members would unite, not only in thanking the Author for the interest he had shown in the Institution by con-

Sir Benjamin Baker. tributing this valuable Paper to its Proceedings, but also in assuring him, on the part of British engineers, that they wished him a long life, and a continuance of energy to carry out the useful works which had hitherto distinguished his career.

Mr. Matthews. Mr. WILLIAM MATTHEWS, of Westminster, said the subject of the Author's excellent Paper was not one which lent itself to much discussion. A combination of Mr. Eads with the Author, naturally led to the works being well designed and efficiently executed. It was impossible not to be struck with the excellent results produced. From the diagram of the entrance, it might be concluded that an extension of the moles would be required at some future date, as there had been a considerable accretion to the south of the south jetty, which was no fault of the works. The moles had gone quite far enough to effect the present object; and when occasion required, there would be no difficulty in prolonging them. It was evident, from the two cross-sections of the jetties, that as the slopes were 3 to 1, the structures could not be exposed to any great wave-stroke, as experienced in this country and in the colonies. If they had been exposed to heavy seas, he thought it would not have been advisable to carry them out on parallel lines. They were admirably suited to the conditions which prevailed; but where there was a heavy sea running on to moles, he thought it preferable that the jetties should be curved as at the Sulina mouth. By carrying out the moles in the way shown in *Fig. 12*, two excellent wave-traps would be formed, so that undulations entering between the moles would be dissipated in the traps, instead of extending up the river. Two river entrances in New Zealand had been treated by Sir John Coode in this manner, with satisfactory results, the wave-traps on each side of the moles increasing the efficiency of the works, and preventing runs up the river. He observed that the Author had been troubled with the *teredo*, as others had been in many places. When Sir John Coode commenced the works at Colombo twenty years ago, he put up a temporary jetty to land materials. The Baltic fir timber was creosoted with 12 lbs. to 14 lbs. of oil per foot. This jetty was completely riddled with the *teredo* in two years, and had to be rebuilt. Creosote was

Fig. 12.



Mr. Matthews. clearly not a preventive where the worm was very active, for in many of the holes, in some of which the finger could be put in and turned round, they could smell the creosote. His firm had found that there was no timber and no preservative that was proof against the ravages of the *teredo* in some tropical waters.

Sir Edward Carbutt. Sir EDWARD CARBUTT, Bart., had visited New Orleans and several other places with the Author, and had seen the way of forming the mattress for carrying the stone. It was very effective at the Mississippi, and he thought, therefore, that it would also be very effective in the case described. He had not visited Tampico, but he had spent some time at San Luis Potosi, where, although everybody was anxious that the scheme should be a success, everyone said it was not likely to be so, since it was thought that, even if the jetties were got out, they would make up in time. He was glad to hear that the channel was likely to keep open, owing to the strength of the current; but he agreed with Mr. Matthews that the time would come when the jetties would have to be considerably extended. The same question had arisen in another case. The engineer of the Nicaragua Canal, Mr. Menocal, had discussed with him the various difficulties met with in that work, one of which was the entrance of the canal into the Gulf of Mexico. The conclusion at which Mr. Menocal had arrived was that he would have to keep on extending the piers. With regard to the *teredo*, at San Francisco nearly the whole of the harbour work was being gradually destroyed. The timber there could not last more than two or three years, and it had been decided to try iron piles.

Sir Leader Williams. Sir E. LEADER WILLIAMS agreed with Mr. Matthews that the jetties would have to be extended. The longitudinal section showed that the bar was diminishing in height and travelling seaward. There were 24 feet of water at present on the bar, but there were 30 feet to 36 feet nearer the town. The work was exceedingly interesting; but it should be remembered, in applying works of that character to other rivers, that the watershed was about 36,000 square miles, with a rainfall of 40 inches, between Tampico and the base of the mountains, providing enormous scouring power. No doubt there were long intervals of drought, but that was the case with tidal rivers in England. He had had a great deal to do with the Dee and other rivers where there was the same struggle with Nature. During periods of drought, there was a good deal of deposit; and then big winter floods came down, like those described in the Paper, and scoured it out. The confining of the channel greatly increased the scouring power. The cross-sections showed the gradual progress of the depth of the

Sir Leader Williams. channel, till at the bottom there was very little difference; so that in August in one year and January in another, the bed was almost exactly on the same lines. It was a proof of good engineering to maintain a channel so truly as that with varying conditions, with large floods coming down, with a heavy rainfall, with a great drainage area, and long droughts. He hardly thought that mattresses were absolutely necessary. In very rough weather they were no doubt an advantage, being the nucleus of the work, and in that sense they were useful. The question of constructing training-walls was an important one. The case of the Ribble was perhaps more interesting to English engineers than any other. There was a great struggle going on in the endeavour to get through the large delta at the mouth. In the case mentioned in the Paper there was no delta. There were varying changes outside, but nothing comparable with the great mass of sands which he had explored the previous week in the Ribble estuary. A commission of eminent men had struck out a straight channel; but unfortunately for Preston they had not a large backwater, as in the case of the Tampico harbour works. The tidal influence did not extend a long way above Preston, and there was no large area to contain the water required. Even the Dee was better off in that respect. An enormous area existed in the Mersey to empty through the narrows at Liverpool. Although it would be difficult to say what dredging might yet have to be done, he should like to bear his testimony to the great success of the dredging at the Mersey bar. The originators of the Manchester Ship Canal were almost as much interested in the depth of the bar at Liverpool as the Liverpool people themselves, except that at present they had not so large a trade. Years ago he was one of those who thought that dredging a channel through the bar at Liverpool, without some training-walls to support and maintain it, would be a failure; and he believed that the great bulk of the engineering profession were of the same opinion. There were some who adopted the other view, and they had proved to be right. Where there was not a great length of bar or delta to dredge through, with a great reservoir behind, which gave plenty of scouring power, if the channel was dredged, the hydraulic mean depth and power were so increased that, when once it was made, it would maintain itself. He had thought that at the Mersey bar, gales of wind would have brought the sand in, tending to close up the dredged channel. The sand-pumps proved of great value in the early part of the work; but with sand-pumps, it was necessary to have sand of good specific gravity to

Sir Leader Williams.

settle quickly. Having got through the surface of the bar of the Mersey, strata of a muddy character was encountered, which took longer to settle. A sand-pump had been tried on the Ship Canal at Manchester, where there was a good deal of sewage, silt, or light deposit. The surface water had to flow over the sides of the vessel into the river, and nearly all the mud flowed over with it. After keeping the sand-pump at work about a day, very little stuff was found at the bottom of the hoppers; but in cases like the Mersey, the Dee, or other rivers where there was sand of a heavy character, sand-pumps might be used with great advantage. Training-walls, however, were the cheapest plan, as, when well constructed, they maintained the channel without cost. If they could be carried out economically, if there was stone and other material handy, no better means could be employed for improving a river than those so successfully adopted by the Author.

Mr. Wolfe Barry.

Mr. J. WOLFE BARRY, C.B., Vice-President, felt sure the Institution would congratulate the Author on his brilliant success as a harbour engineer. The Paper was eminently practical, and appealed to a large class of engineers who were engaged in important harbour works like those described. Although Papers on theoretical subjects were gladly received, yet a Paper like the present was specially welcome, as it gave all the arguments and reasons, both theoretical and practical, that had induced an engineer to adopt a particular mode of construction. All would admit that the works in question had been laid out on the best scientific principles. There might be some little matters for criticism, such as that to which Mr. Matthews had alluded in regard to converging moles instead of parallel piers; but, like Mr. Matthews, he thought the Author had all the circumstances well in his mind when he designed the parallel piers. Probably he considered that the waves entering the end of the harbour of Tampico could not be very heavy. Mr. Matthews' surmise in that respect was presumably right, and if so, the provision of a wave-trap was not necessary. When they observed the great care with which the works were designed, following the investigation of littoral currents, the floods, the transporting power of the river, and all the various circumstances to be dealt with, they might feel assured that this matter relating to the piers had not escaped the Author's notice. Owing to the prevailing winds in that locality, it was found that there was a well-developed littoral current, and also that, owing to the large amount of back-water from the river, there was no difficulty, if the scour of the back-water was directed upon the bar, in deepening the bar by pushing forward

Mr. Wolfe Barry. the eroded material into such a strong littoral current as would sweep it away and keep the entrance open. Something might be said against Sir Edward Carbutt's and Mr. Matthews' view as to the necessity for the prolongation of the piers. It must be a matter of balance of power which could not, he thought, yet be predicated, whether the littoral current would be sufficient under the new circumstances to take away the deposits brought down by the river. He should rather incline to the hope that the balance of power would be in favour of the strong stream which issued from the river, and would keep the channel open. That, however, could not be considered as in any way settled. A short time ago, the valuable services which Sir Charles Hartley rendered to the scheme for the improvement of the Mississippi, so ably carried out by Mr. Eads, had been brought before him, in the correspondence between Sir Charles Hartley and Mr. Eads and some of the promoters of the Mississippi scheme under Mr. Eads' direction. At the time when Mr. Eads stood almost alone in contesting the views of the Government engineers, Sir Charles Hartley came to his aid with most apposite suggestions, and with extremely valuable information gained at the mouth of the Danube. He pointed out how, contrary to the definite assertions of the Government engineers on the subject, there was probably a well-developed littoral current at no great distance from the shore-line, amply sufficient to maintain the outlet channel of the Mississippi if it could be developed by jetties projecting into the sea. Observations were, accordingly, made, and the anticipated current was found to exist. He had seen a letter from Mr. Eads to Sir Charles Hartley, expressing the warmest thanks for the yeoman service rendered in reference to that very uphill fight. Mr. Eads might perhaps have been able, unaided, to convince his fellow-countrymen; but his task of converting them was rendered immensely easier by the extraordinarily able report which Sir Charles Hartley made. As English engineers, they ought to be cognizant of that important fact; and nobody recognized it more thoroughly than Mr. Eads himself. The Paper under discussion presented an example of a good littoral current with practically no tidal action. In this case, a current was developed by prevailing winds; and it was to be specially noted, after the recent discussion on littoral drift, that here was one of those littoral currents which were so valuable to engineers in the construction of harbour works, without the action of great tides, which had been invoked as the only practical means of maintaining a littoral travel. He should like to know what opinion the Author had formed after experience

of the construction of mattresses; it seemed to him that it was open to question whether any advantage was gained by the use of mattresses in these works. In other places mattresses might be very beneficial; but he doubted whether, if the Author's work had to be done again, they would be used at Tampico. It rather appeared they were adopted when the Author thought they would be more easily built and compressed, and would not be so expensive as they turned out to be. As in so many other cases, that seemed to be one of the circumstances to be dealt with and judged of by local conditions. The cost of the large stone appeared to be as high as 9*s.* 3*d.* per cubic yard; of the small stone 7*s.* 5½*d.*; and of the concrete blocks £2 1*s.* 8*d.* He could well believe that mattresses might have been introduced for the sake of cheapness, when stone had to be brought from such a great distance as 78 miles at such a heavy expense. Mattresses were no doubt useful in some positions for resisting the scour which attacked the toe of embankments and endangered the whole structure; but he did not gather that that was altogether the case with the Tampico harbour works, although it was right to notice that the Author gave very high velocities of the stream in times of flood. Still such a stream could only attack the mole in course of construction, and before the stonework surrounding the mattresses was finished. To that extent perhaps mattresses might be desirable during the progress of the works; but looking at the fact that the sand seemed to have been hard and solid, he could not help thinking that, but for the idea of economy, mattresses would not have been adopted. Another point was the great importance of selecting, as the Author had selected, stone of heavy specific gravity for sea-work, a matter which had not been adequately considered. The Author had stated that the limestone was selected largely on account of its being as heavy as granite. In the construction of any sea-work, it was an enormous advantage to have a stone of high specific gravity. He remembered, many years ago, having been struck by a device adopted by Mr. Messent, at the piers at the mouth of the Tyne, of mixing mill cinder from ironworks with concrete in order to obtain, by the admixture of the heavy iron ingredient, a high specific gravity for the concrete blocks which protected the breakwater. As English engineers, they highly appreciated the courtesy shown by the Author to the Institution in contributing a Paper which was not only valuable in itself, but was a record of an extremely successful work that was a credit to the engineering world. Mr. Wolfe Barry.

Mr. Edward Jackson said one feature in the Author's work which had contributed greatly to its success was in making provision Mr. Jackson.

Mr. Jackson. for a rapid method of execution. He did not refer merely to the details of the appliances adopted and the mode of carrying on the work, but also to the provision made for the materials being brought to the ground over-night; so that during the working-hours of the day, there was no waiting or loss of time. On a sandy shore of that kind, it was of importance, when the work was once commenced, that it should be pushed forward rapidly, otherwise troubles would arise such as those to which Mr. Barry had alluded, the littoral drift becoming arrested, and causing a vast amount of expense and extra work. As it was, it was carried out before any material obstacles had come in the way. It appeared from the price given for the mattresses, namely, 6*s.* 2*d.* a cubic yard, that their cost exceeded the cost of the stone by about 1*s.* a cubic yard. Taking the average cost of large and small stone, namely, 8*s.* 4¼*d.* a cubic yard, the cost of the mattress—which was 50 per cent. more than was estimated, through unlooked-for consolidation—was really more than that of the stone. The question then arose whether it was worth while to use these with their intricacies and contingent arrangements necessary for sinking them, together with the risk of their being damaged or carried away by the sea, instead of filling up the hearting with a mixture of different-sized stones. Another point was the steep slopes at which the channel stood, or would eventually stand. The borings indicated a depth of 20 feet or more of sand in the bed of the channel; and he imagined that it must be fine or silty sand, because the Author had stated that it was not suitable for making concrete. It remained to be seen in the future whether the remarkable enlargement of the channel between the jetties, which had taken place since the work was in progress, would, owing to increased scour due to increased depth or exceptional floods, still further widen the channel, and encroach upon the sides, and so undermine the slopes, especially along the south jetty, to an extent sufficient to cause the jetties to settle, or slip into the channel. The works, however, had been finished more than three years, and had, up to the present, been most successful, as shown by the plan and sections of the channel; so that perhaps such forebodings were not warranted.

Mr. Deacon. Mr. G. F. DEACON thought some injustice had been unintentionally done to the Author, from the fact that the survey from which Fig. 9, Plate 4, was compiled, was evidently made before the last part of the Paper was written. After describing everything up to the date of the survey, the Author stated that a flood took place in August 1894, which reduced the depth immediately in front of the jetties to 19 feet of water, increased to

$21\frac{1}{2}$ feet at the end of the month; and the survey of January 1895, Fig. 9, Plate 4, showed a clear, but somewhat tortuous channel of 24 feet. No later chart was given with the Paper; but the Author added that in August 1895, there was 24 feet of water, and before February 1896, the littoral current had swept away the whole of that deposit; and from December 1895 to February 1896, a navigable channel with a minimum depth of $27\frac{1}{2}$ feet was maintained at the end of the jetties. The tidal diagram was given for a whole year, during eight months of which the tide was almost wholly below the zero level, which he assumed to be the mean-tide level. In one month only, namely in June, the tide had a range of double that which occurred in any other month; and about half that range was above zero, and half below. It was a condition of things he had never seen elsewhere, and he thought it should be explained more fully. Mr. Deacon.

Mr. W. SHELFORD said, with regard to the mattress work, it appeared to him that, as the piers were founded upon sand, the Author very properly took the precaution of using mattresses, in order that he might not lose the foundation of his piers as soon as he commenced to throw in the stone. He had himself, in the Fen district, used mattresses, copying the Dutch practice to some extent. The most trying case was where he had to put a weir across a tidal channel with a bottom of silt and sand of unknown depth, where the bed was easily scoured by the tide which ebbed and flowed over the weir, and submerged it even at low water. He began the work by forming several mattresses, and placing them on rafts in position, one after the other; and at the turn of the tide at high water, he lowered them rapidly in their places with stones upon them. The result was that when the tide began to ebb, the current increased from 4 miles an hour up to 10 miles. Nevertheless, that weir was raised by a succession of mattresses to the desired height above the river bottom, and stood until it had to be taken up for reasons irrespective of the weir itself, when great difficulty was found in removing it. All the mattress work in the Fens consisted of fascines or faggots, carefully made, and costly. He did not gather that the brushwood used in the Author's work was first of all made into fascines; if so, it would not have compressed so much as stated. The cost was not very clearly described in the Paper. "The final estimate to the contractor"—whatever that might mean—"made on the 1st January 1893, was £293,989;" whilst the final cost, which apparently included all expenses, general, incidental, engineering, maintenance, etc., came to £617,543. There was a very wide dis- Mr. Shelford.

Mr. Shelford. crepancy between the two. The one might possibly mean the first cost of the works, and the other the cost of maintenance for a few years, which might properly be included in it. He, however, thought that not much had been saved directly by the use of faggots; and it was possible they were only used as hearting, and not carried to the toe of the stage. In that case, a very large quantity of stone might have gone into the sand at the foot of the slopes beyond what was shown in the sections. That was almost certain to have been the case if it were a sand bottom as described, and would account for the apparently heavy cost charged to maintenance.

Sir Guilford Molesworth. Sir GUILFORD MOLESWORTH could confirm what Mr. Matthews had said with regard to the action of the *teredo*. He had put down some jarrah in a temporary jetty at Colombo, and found that in less than two years it was thoroughly honey-combed. Jarrah was said to be a timber which withstood the action of that insect, and in some localities it might do so. In other places, the action of that insect might be much more intense; and possibly on the coast of Australia, where it was said to have withstood that action, it was due to the fact of the insect being less active. It had often been said that a wave did not move loose stones at a depth of more than 12 or 14 feet. In Madras harbour, which he had inspected for the Government of India after the accident which happened to it, he descended in a diving dress and found that large lumps of laterite, nearly a cubic foot in size, had been moved by the cyclonic wave. He was able to put his hands almost as far as he could reach, underneath where the loose blocks of laterite, forming the rubble base, at a depth of 24 feet, had been washed away from under the great concrete blocks composing the superstructure.

Dr. Corthell. Dr. E. L. CORTHELL, in reply to the Discussion, wished at the outset to express his high appreciation of the general approval of his Paper, and of the works described, and especially of the very kind remarks in regard to himself. The prediction made by Mr. Matthews as to the need of an extension of the jetties, owing to the advance of the foreshore, would probably not have been made, had it been possible to have presented a longitudinal profile of the channel through the bar, and of the sea slope, in November or December 1895. It would be noticed, in *Fig. 7*, showing the depths in the jetty channel, that the last date was January 1895, as no complete survey was available subsequently to that date to compare with these longitudinal sections. Partial surveys, however, made at different times and subsequently, from which a model of the channel was made in December 1895, showed

that there had been a marked deepening in front of the works, and that if the present section was drawn, the line would probably fall below that of May 1890, on the outer slope of the bar in the sea. The model of December 1892, which was made subsequently to the discharge of a large amount of heavy material eroded by the river from the channel during its formation, showed an extension of the foreshore immediately in front of the jetties. The model of November 1895, showed that this had been entirely swept away by the action of the currents across the sea ends of the jetties. The current that had performed this work was not the true littoral current of the Gulf Stream, but a much stronger current flowing in the opposite direction, caused by the persistent "northers" referred to in the Paper. He was of opinion, from a careful study of this current in front of the jetties, that no extension of the works would be required for many years. The accretions south of the south jetty had not advanced towards the end of the jetty, beyond the position shown on the chart, for the last two or three years. The reef which was the result of this accretion had become stable, and no further advance of it was expected; and the reef also, or shore-line, on the north side of the north jetty, had not advanced during the last two or three years, and had evidently become stable. The reef on the south side, and all the immense deposits which had occurred in that vicinity, were largely produced by the discharge of sedimentary matters, either from the river itself, or from the channel during the development of the channel. The reef upon the north side of the north jetty was caused by the littoral drift of sand along the shore towards the jetty. Dr. Corthell.

The remarks made by Mr. Matthews and others, in regard to the *teredo*, had no great bearing upon the main question of the permanency of the works, because, as stated by him on pages 251 and 252, "The amount of creosote in the piles was 12 lbs. per cubic foot, which was found to be sufficient, as it was only necessary to preserve them during the construction of the work, or about three years." It might be added that the piles of the trestle outside those under the rails were not creosoted, and yet very few of them were eaten to such an extent by the *teredo* as to require renewal. The presence of fresh water, specially muddy water, in this and other sediment-bearing rivers of the Gulf of Mexico, made the ravages of the *teredo* much less than at points where such conditions did not exist; and at such exposed points, a charge of 16 to 18 lbs. per cubic foot, had been found generally sufficient to extend the life of the timber from about two years to an average of fifteen years.

Dr. Corthell. In reply to Sir Edward Carbutt, the engineer of the Nicaragua Canal, in reference to his own work at Nicaragua, would no doubt have to continue extending the piers, but not particularly on account of the *teredo*, although the *teredo* had already practically devoured the work there, but on account of the rapid advance of the littoral drift seaward. As to the use of mattresses, to which reference had been made by several speakers, he would frankly say that if he had to do the work again, now that he was acquainted with the character of the brushwood, he would not use it, except for laying a flat foundation for the superimposed stonework, as the cost of it was fully as great as that of the stonework itself, on account of the extraordinary compression which followed the loading of it with stone. He was decidedly of opinion that nothing but permanent, parallel jetties would have removed the changeable sandy bar in front of the entrance of the Pánuco River; and he further considered that could this bar have been removed by a number of powerful dredgers, so as to form the present channel, the first flood would have refilled the channel; and the lateral action of the winds upon the shoal and movable bar on either side would have assisted in filling up the channel, and so would have obliterated the expensive dredging work. The very appreciative remarks of Mr. Barry, rendered it unnecessary for him to reply to some criticisms made by others. Mr. Jackson spoke of the "steep slopes at which the channel stood." These slopes were not so great as they appeared to be from the cross-sections, in which the vertical scale was greatly exaggerated in order to bring out the irregularities of the channel; but with a natural scale, the slopes would have appeared more stable. Mr. Deacon assumed that the zero level was the mean-tide level; but the zero for all depths of profiles and sections in the Paper was mean high-tide, or average flood-tide, as stated at the foot of the tidal diagram, *Fig. 2*. The fluctuations in this tidal diagram were due in part to the varying conditions of the tides, but also to certain extraordinary conditions which prevailed during the year they were taken. On pages 257 and 258, he had said that, "During one of the floods in 1892, the river at Tampico was raised 2 feet above the level which would have been reached by a similar flood before the jetties were built," for the purpose of showing how the jetties, in connection with the still unremoved bar, backed up the waters in times of flood. The automatic tide-gauge was at the original mouth of the river. In *Fig. 11* the slope of the river during the flood of July and August was plainly indicated; and it would be seen that, at that time, the reading on the automatic tide-gauge

showed an elevation of the water surface of more than 2 feet above the level of the gulf outside the jetties. This flood, as stated below *Fig. 11*, removed the bar entirely, and gave the river the freedom of discharge which its normal conditions required, preventing further abnormal elevations of the water surface in times of flood. Dr. Corthell

The rapidly increasing commerce of the Port of Tampico had led the Government to enter into a contract, in August 1895, with the Mexican Central Railway Company, to erect a new fire-proof Custom House, wharf, and other facilities for the despatch of business at Tampico. The buildings were to be of substantial construction, with all the improved devices for handling goods; and the estimated cost was about $1,250,000. The Custom House was to be 984 feet by 121 feet, and the wharf 1,148 feet long and 49 feet wide, extending out into the river, so that vessels of 24 feet draught could be moored alongside.

Mr. Shelford considered the estimates of the cost of the work required some explanation. The final estimate to the contractor, made on the 1st of January 1893, included all the construction work covered by the materials, and the prices of the same given on page 254, and certain extra amounts for some additional work. The following statement embraced a summary of items of what might be called extraordinary outside expenses, which rounded up the total cost of construction two years after the works were completed. The cost was given in United States currency, or gold, of the Tampico Harbour Works and property to the 31st of December 1894, and related to the construction at the time of the completion of the works, there being very little in the amounts in the way of maintenance or repairs.

	$
Preliminary expenses	3,299·38
General expenses	62,529·36
Engineering	77,132·34
Construction of jetties	2,049,187·31
Office and headquarters buildings	13,487·42
Wrecking and dredging	101,066·70
Real estate	44,098·18
Railroad extension to La Barra	215,971·80
Tracks at Doña Cecilia	23,783·51
Wharves and docks	51,779·90
Bond interest	357,101·85
Subsidy expenses	1,822·80
	3,001,260·55
Less credit balance of miscellaneous interest account	171,192·57
	$2,830,067·98

Correspondence.

Mr. Carey. Mr. A. E. Carey remarked that the material to be scoured away from the mouth of the Pánuco River appeared to be the sediment of land-washings rather than that due to littoral movements. Since the construction of the La Guaira harbour works, the foreshore, which had formerly remained constant so far as accurate records showed, had been changing its contour in consequence of the steady action of the north-east trade-winds under altered conditions, and also of those occasional "northers," the suddenness and violence of which were almost incredible. Similar movements doubtless resulted from the action of the same forces throughout the Gulf of Mexico. He would ask why the southern jetty was constructed to overlap the northern. Judging by the natural conditions, it would appear that the sweep of the wave-currents southwards would be greater in shoaling effect than that of the Gulf Stream current northwards. On the north side of Vera Cruz Harbour, a mole was being projected to the island of San Juan d'Ulloa; and at the time of his visit in 1893–4, the building of the southern mole appeared doubtful. If the construction of this south mole had been abandoned, the harbour would have become simply a silt-trap, and shoaling would probably have been rapid. The northern arm was, however, considered the more important both as to shelter and drift. In the comparative sections given in *Fig. 7*, a ridge between the jetties occurred at about the 8,000-foot line. This ridge did not vary greatly during the years 1892, 1893, and 1895, being rather shallower in 1895 than in 1892. It would appear as if some deposit were taking place from this point seawards. Would not a slight contraction of the sea-entrance of the jetties have been judicious, in order to counteract such action? Little was said by the Author of any dredging operations. His great aim appeared to be to control and render effective the river forces, in order to scour the harbour mouth clear; and aided by the great flood of July 1893, he had effected a conspicuous success. Some progressive shoaling of the foreshores north and south of the harbour was obviously to be anticipated; but this shoaling (provided the depths now attained in the channel between the jetties could be maintained or increased by natural scour) would probably reach its limit without impeding the results already achieved. He had gathered, when in Mexico, that the harbour of Tampico would always be handicapped by climatic

conditions. English officers of the Mexican Navy had given graphic accounts of the voracity of the mosquitoes of the Pánuco River. The town of Vera Cruz, which had so bad a reputation on this score, was now fairly well drained and comparatively healthy; but the completion of the harbour, and the creation of an area of enclosed water close to the town, would certainly not tend to increase its healthiness. Mr. Carey.

Mr. W. DYCE CAY thought more information as to the maintenance of the jetties would be interesting. The current inside them, and the waves outside, would be apt to undermine the toes of their slopes; and longitudinal rows of piling would be required to keep up the body of the work as the toes sank. The Paper did not give the means of forming an estimate of the cost of consolidating the foundation of a jetty on sand by means of mattresses; but from the information given, and the cost of similar work in Holland, it appeared costly. He considered that in cases where coarser sand and shingle, or broken stone, quarry rubbish, or other material, such as would be suitable for concrete, could be obtained, which was not the case, however, at Tampico, a bed of such materials without cement formed a reliable base for the rubble superstructure and its slopes, without the use of mattresses, rows of submerged piling being driven through the shingle to divide it into compartments. In addition to piling, he had found large bags of concrete very effective in maintaining the toes of paved slopes, and with floating plant they were easily laid down where required. Mr. Dyce Cay.

Mr. J. L. HOUSTON observed that the Paper formed an interesting and valuable account of a most successful piece of work. The time occupied in the construction of the jetties, two and a half years, was a proof of excellent organisation. Their cost, about £46 per foot, seemed, on the other hand, excessive, probably due to expenses other than the net cost of the work. The employment of mattresses, he considered almost indispensable in a work of this kind in shifting, silty sandbanks. Not only did they hold the loose rubble together, but they also consolidated bad ground in a remarkable manner. It was evident that no really heavy seas had to be provided for, as the stone employed seemed to have been comparatively small, and could not have stood even at a slope of 3 to 1 had there been much sea. These improvements could not, in his opinion, be regarded as of a permanent character. The improved channel might maintain itself for many years; but in the end the shoals were likely to reappear, and prolongation of the jetties or other measures would be necessary. There were Mr. Houston.

Mr. Houston. two causes at work, both tending to this result, one being the silting effect of the littoral current, which had already not only advanced the shore-lines, but shown still more menacingly in the "reef above water," and shoaling of the water about half-way down the south jetty. The other cause was the silt brought down by the river, which, as soon as released from the guidance of the jetties, was checked by the sea current and the waves, and tended to form shoals near the entrance. This action was evidently also in progress, as shown by the two comparative plans.

Some years ago he had occasion to study the problem of the opening of the mouth of the River Magdalena, where the conditions were very similar to those of Tampico, only on a much larger scale, and probably under much less favourable conditions. This river brought down enormous quantities of silt; and its mouth was obstructed by extensive and constantly shifting banks, although the current was so powerful as to discolour the water many miles out at sea. In the flood season, the current was strong enough to cut its way out to deep water, often with a clear channel of 40 or 50 feet in depth; whilst in the dry season, the fresh-water stream being quickly checked by the sea current and the waves, the silt was deposited; and frequently there was not more than 10 feet of water on the bar. The works proposed for this were similar to those at Tampico, namely, two parallel jetties with the addition of internal training works. The jetties were to be of stone and fascine work; but the exposed face of the windward jetty was to have been protected by 25-ton concrete blocks thrown down from staging. Notwithstanding a probable lack of finality, such works as that which formed the subject of the Paper were of the greatest importance and utility. In this case a large trade had been created, which would justify and render easy works of maintenance or extension should they be required.

Mr. Sutcliffe. Mr. G. W. Sutcliffe considered the width of channel small, having regard to the area of the watershed, even when allowance was made for the fact that the discharge was but little interfered with by the tide. From the figures given, the channel would, however, appear to be ample for the duty required of it. It would be of interest to know how the stated maximum flood discharge was obtained. 153,000 cubic feet per second would give a mean velocity of only 6 feet per second in a channel 1,000 feet by 25 feet, or say a maximum velocity of 7·5 feet per second, equal to about 5 miles per hour. But it was stated that a steamer running 12 miles per hour could not face the current. It would therefore appear, either that the captain of the steamer made no

serious attempt to enter the river, or that the quantity of water Mr. Sutcliffe. discharged was much greater than stated. One day's discharge, at 153,000 cubic feet per second, was equivalent to a rainfall of 0·158 inch over the whole of the watershed, or to a rainfall of 3½ inches if the maximum discharge were maintained throughout the twenty-two days of the flood. This again appeared to be a very moderate quantity. It would therefore seem probable that the velocity of current was really higher than it was believed to be. If this was so, there was a liability to scour out the foundations of the breakwaters, so that an incessant watch should be kept, and any signs of settlement should receive immediate attention. The comparatively short time occupied in opening out the channel also supported the suggestion of excessive scour.

An explanation of the occurrence of one tide only per day would be of interest. The position of the tide-gauge should also appear upon the plan, and a note made, in case two positions were adopted for the gauge. The tidal diagrams for 1892 showed traces of the second tides in several cases, but these were very pronounced in the diagrams for 1893.

The construction of the breakwaters appeared to be good, but the strength of the whole depended upon the supporting timbers and the stone loading. The small iron rods were only useful temporarily. The supporting timbers would be of great use in case of scour, and to have omitted them would have been bad policy. It was stated by the Author that it was only necessary to preserve the staging-piles for three years. Some means should be available for transport of material to the breakwaters at any time. Perhaps floating craft might be used, otherwise the staging and railroad should be maintained in working condition. Having regard to the meagre information obtainable as to the river discharge before undertaking the work, it would appear that a greater margin should have been allowed. The work, however, was of great interest as a bold project, well carried out in a limited time.

Dr. Corthell. Dr. Corthell observed, in reply to the Correspondence, that both jetties with their foundations had been laid to the same length. During the construction of the works experience had been gained in the action of shore-currents, and it was found that although the true littoral, or Gulf Stream current, was northerly, the southerly currents, due to the persistent "northers" prevailing during the entire winter season, sometimes with great violence, deflected the littoral currents and produced a much greater effect in front of the jetties. "The sweep of the wave-currents southwards" would not produce a shoaling effect, as Mr. Carey intimated,

Dr. Corthell. but a scouring effect, which was very marked. It had deepened the water immediately at the end of the northern jetty to such an extent that it had been deemed advisable not to build the jetty in such very deep water, but to leave the southern jetty to its full length in order that it might act as a training-wall to conduct the fluvial current as far seaward as possible. That this decision was well taken, subsequent events had proved. Further remarks were made by Mr. Carey upon the "progressive shoaling of the foreshores north and south of the harbour;" but he stated that it "would probably reach its limit without impeding the results already achieved." The conditions to the present time showed this opinion to be well founded. The climate of Tampico Harbour was not injurious to health; and the business of that port had not been, and would not be, in the opinion of the Author, handicapped by any climatic conditions. The mosquitoes were not so numerous or so voracious as at many other harbours and river entrances where there was a much larger business than at Tampico. The general climatic conditions were much better than at Vera Cruz, where yellow fever seemed to be indigenous and prevailed during all seasons of the year.

In reference to the opinion expressed by Mr. Dyce Cay, that the current inside, and the waves outside, would be apt to undermine the toes of the jetty slope, no such effect had as yet been noticed, nor was it anticipated. As stated in the Paper, the cost of the mattress work was nearly if not quite as much as the rock work, on account of the great compression of the brush that was used in the mattresses. Still he believed it was necessary to make the hearting and foundation of mattress work.

The southerly currents had been, since the Paper was written, quite effective in discharging and removing from the front of the jetties a large amount of material that had been pushed out during the construction of the works. From careful observations of the changing conditions due to the various potent causes actively at work, the channel at the sea entrance of these jetties would not be permanently obstructed at any time by increasing shoals. The reefs which had formed above water on the flanks of the jetties and near the land had attained their utmost limit, having reached the point where the depositing action and the eroding action of the waves were in equilibrium. The maximum flood discharge had been carefully measured at a gauge-station at a suitable place in the river between the works and Tampico; and the work had been performed in the usual manner by instruments upon base-lines and by ranges and floats.

The reason why a steamer could not easily enter the jetties from the sea was plainly shown in *Figs. 10*. On the 20th July, when the slope from the sea end of the jetties was 1·6895 foot to the mile, the measured current was 8·2 miles per hour. On the 24th July the slope was 2·8432 feet to the mile. On the 26th July it was 2·4730 feet to the mile, and accompanied by still greater velocities than 8·2 miles per hour, which would account for the inability of a steamer moving at the rate of 12 miles per hour to stem the current. There was no danger of undercutting the works by this extraordinary velocity, which was found in mid-channel and not alongside the works. Dr. Corthell.

On account of the great size of the Gulf of Mexico, and the comparatively small inlet of the tides at the Florida Straits and at the Promontory of Yucatan, and further on account of the very small range of the tides, only 14 inches, there was no time for the second tide of the day to enter. However, there was usually, as appeared in *Figs. 2*, a trace of the second tide, which during the month, suddenly became the main tide, and the previous main tide became a trace simply. The scantling used for forming the framework of the mattresses was of no material consequence. It was not intended to support anything, and was used simply for the purpose of getting the brush into place under the stonework. The trestle work, which was used for a railway line, had fallen into disuse, as was intended and expected; and for the purpose of maintenance there was now a floating equipment. The information about rainfall upon the watershed was very limited, for no attention had been paid to such observations. Rain-gauges had been placed at several points along the line of the railroad within a distance of 60 miles; but the floods of the river came from the rainfall at much greater distances, which was very variable, not only in character, but also by the month and by the year, and could not be depended upon. The channel had been maintained since the writing of the Paper, and the commerce was still rapidly increasing.

---

7 April, 1896.

No Meeting, it being the Tuesday in Easter week.

SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 2755.*)

(*Abridged.*)

"Trials of an Express Locomotive."

By WILLIAM ADAMS and WILLIAM FRANK PETTIGREW, MM. Inst. C.E.

THE engine upon which the trials described in the Paper were made is one of twenty built from the designs of the Authors for the London and South Western Railway Company, at the Nine Elms Works, for the heavy main-line express trains between Waterloo, Salisbury, Southampton and Bournemouth. These engines run from Waterloo to Basingstoke, a distance of 48 miles, within an hour, and during the summer months accomplish the journeys to Salisbury and Christchurch, distances of 84 miles and 104 miles respectively, without a stop. They have four wheels coupled, and a four-wheeled bogie. The cylinders, placed outside the frames, are 19 inches in diameter, and have a stroke of 26 inches; with a clearance at each end equivalent at the front to 7·7 per cent., and at the back to 6·6 per cent. of the capacity of the cylinder. The slide-valves have a range of 3⅝ inches, with 1-inch outside lap and ⅛-inch lead, in full gear. The coupled driving-wheels are 7 feet 1 inch, and the bogie and tender wheels 3 feet 9¾ inches in diameter. The frames are of mild steel 1 inch thick; and the boiler-barrel is 11 feet long and 4 feet 4 inches in outside diameter, the plates being of mild steel ½ inch thick. Between the tube-plates the length is 11 feet 4 inches; and there are two hundred and forty tubes of 1¾ inch outside diameter. The height of the centre of the boiler-barrel above the rail-level is 7 feet 9 inches. The fire-box is of copper, and is 5 feet 6$\frac{7}{16}$ inches long at the top, and 5 feet 7⅛ inches at the bottom, the height being 5 feet 9½ inches to the bottom, and 5 feet 7 inches to the top of the foundation-ring, and the width 3 feet 6 inches at the top and 3 feet 2½ inches at the bottom. The plates are ½ inch thick except the tube-plate, which is 1 inch thick. A total heating-surface of 1,358·65 square feet is provided, and the grate-area is 18·14 square feet. The working boiler-pressure is 175 lbs. per square inch. The weight on the driving-wheels is 33,488 lbs.,

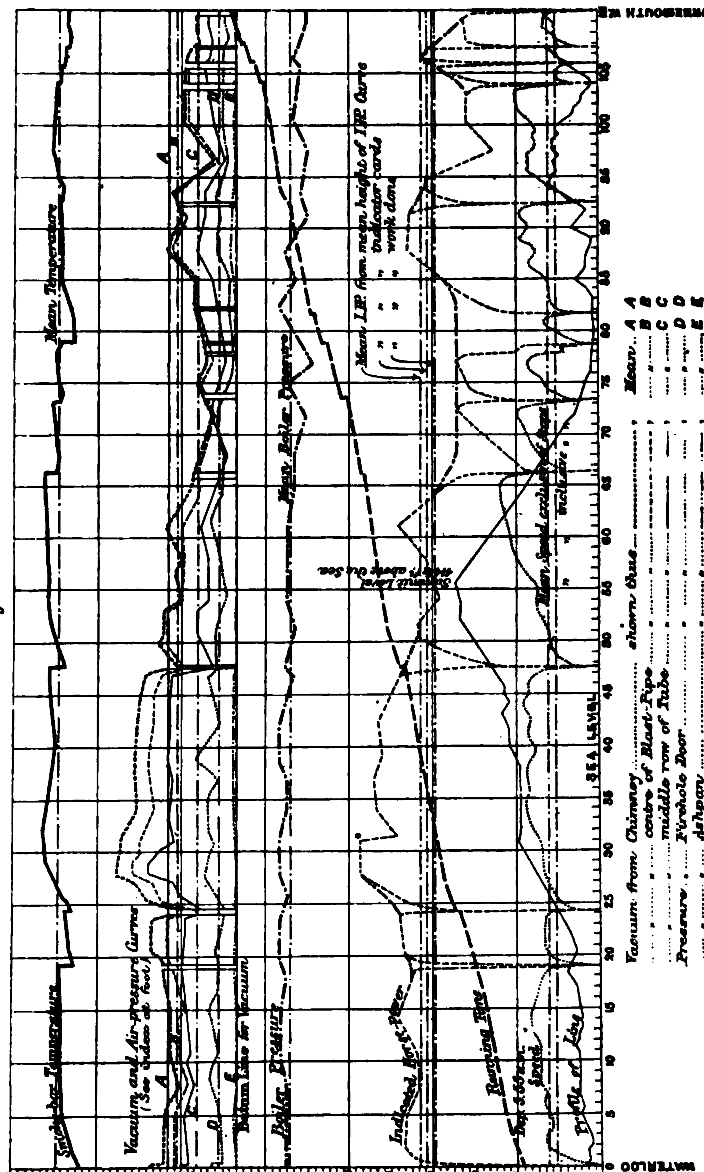
on the trailing-wheels 33,152 lbs., and on the bogie 42,280 lbs.; the weight of the tender full of water and with 2 tons of coal is 74,816 lbs.; the total weight of the engine and tender in working order being 183,736 lbs. The total wheel-base of the engine and tender is 44 feet 3⅛ inches; the extreme length over the buffers being 53 feet 8⅝ inches. The length from the front of the buffer to the centre of the bogie is 8 feet 4¾ inches, from the centre of the bogie to the centre of the driving-axle 10 feet 9 inches, from the centre of the driving-axle to the centre of the trailing-axle is 8 feet 6 inches, and from the centre of the trailing-axle to the back of the frame is 4 feet 3 inches. Steel castings were used where possible in the construction of these engines, thus dispensing with intricate and difficult forgings. The driving-, trailing-, and bogie-wheels, together with all bogie-castings, pistons, crossheads, motion-plate, horn-blocks, spring-hanger brackets and other smaller parts were made of this material. The engines are fitted with the automatic vacuum- and steam-brakes, and also with the Adams vortex blast-pipe.[1]

Five trials were made while the engine was performing its regular duty under ordinary circumstances. The first was on the 9th July, 1891, with the 5.50 A.M. down train from Waterloo to Bournemouth, a distance of 111 miles, with eleven intermediate stops. The load hauled, exclusive of engine and tender, and with no allowance for the weight of passengers and luggage was, from Waterloo to Woking, 24⅜ miles, 239 tons 17 cwt. 3 qrs., from Woking to Basingstoke, 23⅜ miles, 217 tons 6 cwt. 3 qrs., from Basingstoke to Eastleigh, 25¾ miles, 166 tons 16 cwt., from Eastleigh to Brockenhurst, 19 miles, 135 tons 15 cwt. 2 qrs., and from Brockenhurst to Bournemouth, 18½ miles, 116 tons 16 cwt. 2 qrs. The mean load throughout the journey was 179 tons 16 cwt. 3 qrs. The profile of the road is shown in *Fig. 1*, the steepest up gradient being 1 in 99 for 1¼ mile. The speed, indicated horse-power, actual running-time, boiler-pressure, smoke-box temperature and vacuum curves are also shown. The maximum speed obtained was 68·5 miles per hour, while running on a down gradient of 1 in 251, at the sixty-fifth mile-post. The indicated horse-power, as shown by the diagram taken immediately after, at 68 miles per hour, *Fig. 2*, was 480·2, with steam cut-off at 17 per cent. of the stroke, the number of revolutions being 269 per minute. Particulars of the observations made during

---

[1] For a fuller description of the engine see *The Engineer*, vol. lxxix. 1895, p. 244.

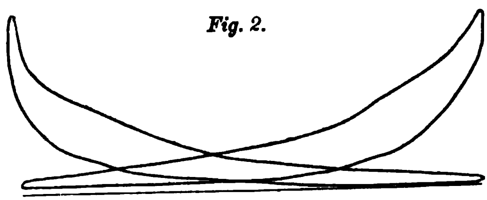
Fig. 1.



RESULTS OF THE FIRST TRIAL.

the trials are given in Table I of the Appendix. The maximum indicated horse-power developed was 684·1, *Fig. 3*, with a cut-off of 29·5 per cent. on an up gradient of 1 in 314, at the twenty-eighth mile-post, the speed being 40 miles per hour, and the number of revolutions 157 per minute. With regard to forced draught, special observations were made during each journey of the vacuum obtained, at the base of chimney, in the smoke-box, on a level with the exhaust nozzle, in the centre of the blast-pipe,

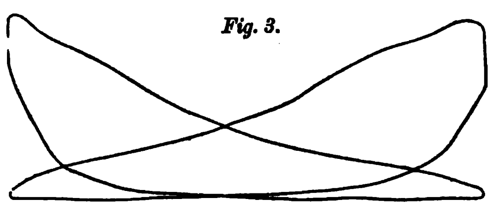
Fig. 2.



Mean effective pressure, 24·37 lbs. per square inch.

in front of the centre of the middle row of tubes, through the fire-hole door, and in the ash-pan. The diameter of gases-pipe of the blast-pipe was 5 inches and its area 19·6 square inches; the area of annular exhaust being 13·9 square inches and its width $\frac{11}{16}$ inch. The temperatures of the gases in the smoke-box was also taken at 1-mile intervals, the maximum being 585° F., and the mean 488·91° F. The weather was fine with a strong head wind.

Fig. 3.



Mean effective pressure, 59·88 lbs. per square inch.

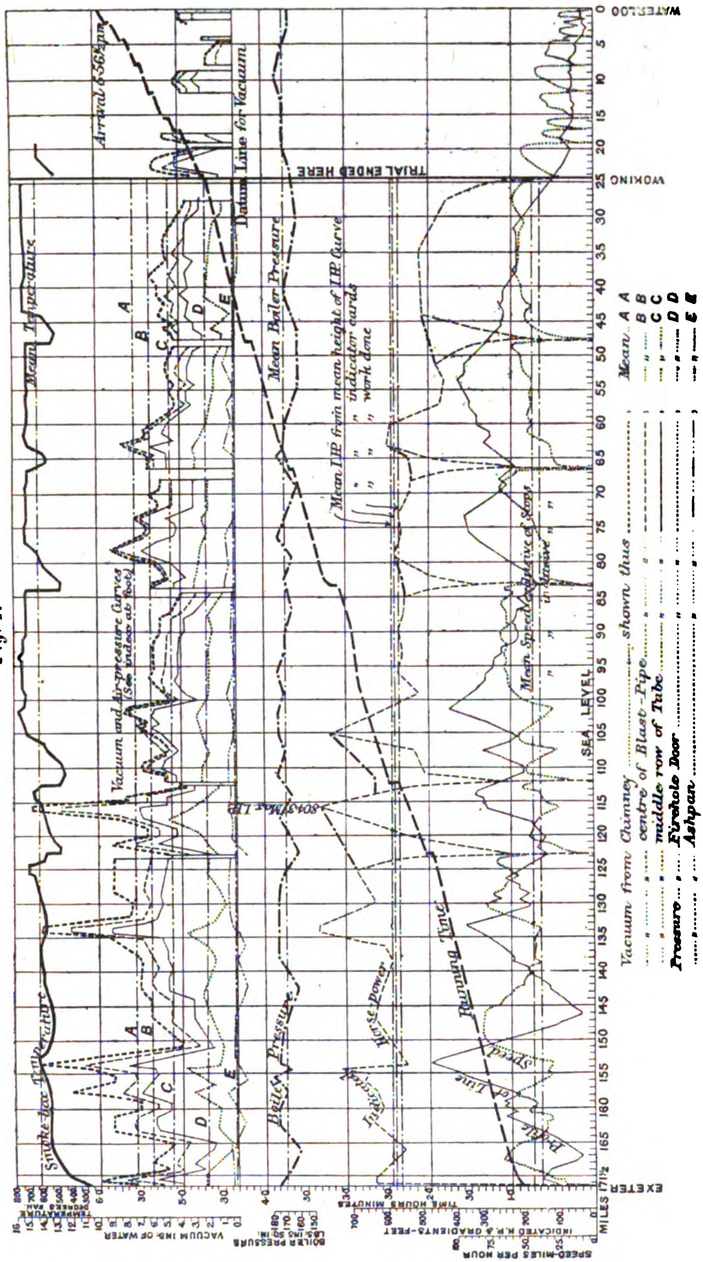
The second trial extended over the return journey from Bournemouth to Waterloo on the same day, the time of departing being 1.55 P.M. Three intermediate stops were made in addition to that at Vauxhall. The load hauled, exclusive of the engine and tender, and with no allowance for weight of passengers and luggage, was, from Bournemouth West to Bournemouth East, 3½ miles, 89 tons 11 cwt. 2 qrs.; and from Bournemouth East to Waterloo, 107¾ miles, 137 tons 11 cwt. 2 qrs. The mean load throughout the

journey was thus 136 tons 3 cwt. 2 qrs. Observations, similar to those recorded of the first trial, were taken, the results being shown in Table I of the Appendix. The maximum speed obtained was 67 miles per hour while running on a down gradient of 1 in 386 between the twenty-third and twenty-fourth mile-posts from Waterloo. The I.HP. taken immediately after this observation, at a speed of 66 miles per hour, was 571·6, with a steam cut-off 17 per cent. of the stroke, the number of revolutions per minute being 261. The maximum I.HP., 610·1, was developed with a steam cut-off of 26 per cent.; on an up gradient of 1 in 249, at the sixtieth mile-post, the speed being 43 miles per hour, and the number of revolutions 170 per minute.

The third trial was run on the 10th July, from Waterloo with the 11.0 A.M. down train to Exeter, a distance of 171½ miles, with three intermediate stops; the load hauled, exclusive of engine and tender, and with no allowance for the weight of passengers and luggage, was 168 tons 7 cwt. 2 qrs. The steepest up gradients were 1 in 70 for ½ mile, and 1 in 80 for 4 miles. The maximum speed obtained was 78 miles per hour, while running on a down gradient of 1 in 100 at the 158th mile-post, when the I.HP. was 517·2, with a steam cut-off at 17 per cent. of the stroke, the number of revolutions being 309 per minute. The maximum I.HP., 803·6, was developed with a steam cut-off of 44 per cent., on an up gradient of 1 in 80, at the 152nd mile-post, the speed being 31 miles per hour, and the number of revolutions 123 per minute.

The fourth trial was made during the return journey from Exeter to Waterloo on the following day, the 11th July, with six intermediate stops, departing at 12.54 P.M. (nine minutes late). Owing to many unforeseen stoppages and delays which occurred after leaving Woking, it was impossible to record several of the most important items. The distance from Woking to Waterloo, only 24⅜ miles, occupied 1 hour 15½ minutes, and the trial was therefore ended at Woking. The load hauled, exclusive of engine and tender, and with no allowance for the weight of passengers and luggage was, from Exeter to Yeovil, 197 tons 9 cwt. 2 qrs., from Yeovil to Templecombe, 244 tons 9 cwt. 2 qrs., and from Templecombe to Waterloo, 195 tons 4 cwt. 2 qrs., the mean load being 198 tons 17 cwt. 3 qrs. The profile of the line and the several curves are shown in *Fig. 4.* The steepest gradient was 1 in 80. The maximum speed obtained was 81 miles per hour, while running on a down gradient of 1 in 80 between the 148th and 149th mile-post from Waterloo. The I.HP. taken just after

Fig. 4.

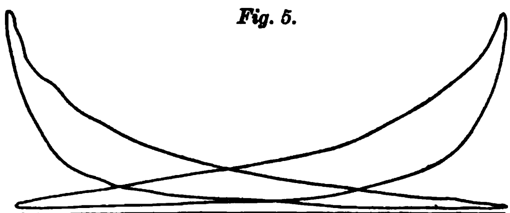


Results of the Fourth Trial.

this, at 80 miles per hour, was 636·2, *Fig. 5*, with the steam cut-off 17 per cent. of the stroke, the number of revolutions per minute being 316. The maximum I.HP. developed was 804·3, *Fig. 6*, the steam cut-off being 48 per cent. This was obtained on the level, and just leaving an up gradient of 1 in 200 at the 115½ mile-post, the speed being 27½ miles per hour, and the number of revolutions 109 per minute. The weather was fine with a moderate side wind.

The fifth trial was run on the 13th July from Waterloo with

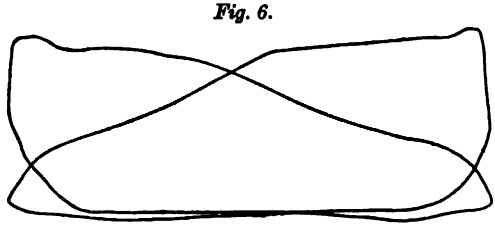
Fig. 5.



Mean effective pressure, 26·75 lbs. per square inch.

the 2.40 P.M. train to Salisbury, a distance of 83⅝ miles, with three intermediate stops. The load hauled, excluding engine and tender, and with no allowance for the weight of passengers and luggage, was 137 tons 10 cwt. 2 qrs. The steepest gradient was 1 in 141. The maximum speed obtained was 75 miles per hour, running on a down gradient of 1 in 178 at the 65th mile-post. The I.HP. taken at the 64½ mile-post, at 72½ miles per hour,

Fig. 6.



Mean effective pressure, 101·75 lbs. per square inch.

amounted to 601·9, with steam cut-off 17 per cent. of the stroke, and the number of revolutions 287 per minute. The maximum I.HP. was 626·1 when the steam was cut-off at 23 per cent. This was obtained on an up gradient of 1 in 264 at the 69th mile-post, the speed being 50 miles per hour, and the number of revolutions 198 per minute. The weather was fine with a head wind.

The speed was taken by a Boyer speed indicator and recorder

driven from the bogie-wheel. This instrument consists essentially of a rotary-pump forcing oil into a cylinder at a pressure dependent on the speed of the train. A pencil is carried by the piston-rod, and is controlled by a spring, the tension of which is the resisting force overcome by the pump. The speed was thus recorded on metallic paper, the divisions agreeing exactly with the mile-posts on the line. The indicator diagrams were taken with Crosby indicators, the springs used having a scale of 100 lbs. per inch of diagram. The instruments were tested before the trials. For the purpose of measuring the feed the tender was first filled and the contents passed out through a Worthington water-meter (previously corrected), a gauge fitted to the tender, being graduated in cubic feet as the water passed out. In calculating the engine efficiencies the amount of steam used by the ejector in connection with the automatic vacuum brake, as also that used by the steam-brake cylinder, has been neglected, consequently the actual engine efficiency would be in excess of that given. The coal was weighed before each trial on to a clean tender, any remaining at the end of the journey being weighed and allowed for.

The Paper is accompanied by eighteen sheets of tracings, from a selection of which the *Figs.* in the text have been prepared. The tracings include copies of the indicator diagrams, taken at frequent intervals during the five trials, which may be inspected at the Institution.

[APPENDIX.

APPENDIX.—TABLE I.—RESULTS OF FIVE TRIALS.

—		1st Trial.	2nd Trial.	3rd Trial.	4th Trial.	5th Trial.
Mean boiler-pressure throughout journey	lbs. per sq. in.	167·5	167·2	171·7	169·4	170·8
Total coal used, exclusive of lighting up	lbs.	3,395·0	3,120·0	4,872·0	4,856·0	2,352·0
„ „ inclusive „ „	„	3,563·0	3,288·0	5,208·0	5,248·0	2,520·0
Coal burnt per hour running time	„	1,136·4	1,270·8	1,309·2	1,467·0	1,315·8
„ „ „ journey „	„	974·7	1,162·8	1,198·2	1,283·0	1,137·9
„ „ square foot of grate area per hour of running time	„	62·54	70·0	72·18	80·89	72·49
„ „ „ „ „ „ „ „ „ journey „	„	53·7	64·1	66·05	70·76	62·7
„ „ I.HP. per hour running time	„	2·31	2·61	2·34	2·52	2·45
„ „ „ „ „ journey „	„	1·98	2·39	2·14	2·20	2·12
„ „ train-mile	„	30·5	28·1	28·4	32·98	28·16
„ „ engine-mile	„	29·5	27·13	27·8	32·21	27·02
Calorific value of 1 lb. of coal	B.T.U.	13,903	13,903	13,583	12,840	13,477
Total water evaporated	lbs.	32,887	27,406	43,104	38,415	21,966
Water evaporated per hour running time	„	11,000·0	11,167·0	11,559·1	11,600·0	12,288·6
„ „ „ „ journey „	„	9,442·1	10,214·0	10,601·0	10,150·0	10,627·0
„ „ „ sq. foot of total heating-surface per hour of running time	„	8·09	8·22	8·5	8·54	9·04
„ „ „ „ „ „ „ „ „ journey „	„	6·95	7·51	7·8	7·47	7·82
„ „ „ I.HP. per hour running time	„	22·4	23·02	20·7	19·94	22·9
„ „ „ train-mile	„	296·28	246·9	251·3	260·9	262·6
„ „ „ engine-mile	„	281·0	234·2	246·2	254·8	252·4
„ „ „ lb. of coal, exclusive of lighting up	„	9·68	8·78	8·84	7·91	9·34
„ „ „ „ inclusive „ „	„	9·23	8·34	8·27	7·32	8·71
„ „ „ „ from feed temperature	„	9·68	8·78	8·84	7·91	9·34
„ „ „ „ equivalent from and at 212° F.	„	11·35	10·30	10·4	9·28	10·96
Maximum I.HP.		684·1	610·1	803·6	804·3	626·1
Mean I.HP. from indicator cards		490·6	485·1	558·1	582·0	536·7
„ „ work done		477·6	475·9	541·0	565·8	522·0
„ „ curve of HP. (mean height)		511·5	497·53	540·14	585·473	540·0
Maximum speed	miles per hour	68·5	67·0	78·0	81·0	75·0
Mean speed, exclusive of stops	„ „	37·0	45·2	46·1	44·45	46·7
„ inclusive „	„ „	31·86	41·34	42·1	38·92	40·44
Actual running time	hrs. mins.	2 59½	2 27¼	3 43¼	3 18¾	1 47¼
„ journey „	„	3 29	2 41	4 4	3 47	2 4

Train-miles		111	111	171½	147¼	83⅝
Engine-miles		115	115	175	150¾	87
Time from lighting up to taking out fire	hours	15	15	8½	8¾	12¾
Temperature of water in boiler at time of lighting up	° F.	205	205	125	165	61
Maximum vacuum at base of chimney	inches of water	8·5	11·0	14·0	15·0	7·0
Mean " " "	" "	4·93	6·43	6·54	7·33	3·83
Maximum vacuum level with the top and in centre of vortex blast-pipe	" "	7·5	7·1	11·0	12·8	6·8
Mean ditto	" "	4·34	4·1	4·21	6·27	4·96
Maximum vacuum at middle of middle row of tubes	" "	6·2	5·8	8·0	9·0	5·4
Mean " " " "	" "	2·84	3·34	3·83	4·77	3·82
Maximum pressure through firehole door	" "	2·8	2·2	3·6	5·0	2·2
Mean " " "	" "	1·25	1·36	1·63	2·16	0·98
Maximum pressure through ashpan	" "	0·5	0·2	0·6	0·8	0·8
Mean " " "	" "	0·08	0·07	0·12	0·19	0·16
Maximum temperature of smoke-box gases	° F.	585·0	575·0	740·0	780·0	740·0
Mean " " " "	"	488·91	494·76	604·62	627·0	575·1
Efficiency of engine	per cent.	9·8	9·55	10·7	11·02	9·61
" boiler	"	77·5	70·0	71·1	66·6	75·5
" engine and boiler combined	"	7·7	6·68	7·6	7·34	7·25
Maximum gradient		1 in 99 up	1 in 90 up	1 in 70 up	1 in 80 up	1 in 141 up
Coal stated includes that used while standing for	hours	3½	5⅓	3¾	3⅔	3¼
		T. C. Q.	T. C. Q.	T. C. Q.	T. C. Q.	T. C. Q.
Maximum load hauled in tons, exclusive of engine, tender, passengers and luggage		239 17 3	137 11 2	168 7 2	244 9 2	137 10 2
Mean " " " " " "		179 16 3	136 3 2	168 7 2	198 17 3	137 10 2
Maximum number of carriages hauled		21·0	11·0	11·0	16·0	9·0
Mean " " "		15·0	10·86	11·0	13·2	9·0
Maximum number of carriage journals		112·0	66·0	74·0	106·0	62·0
Mean " " "		81·4	65·2	74·0	87·4	62·0
Mean load per mile per carriage journal	lbs.	4,948·8	4,680·0	5,096·7	5,091·5	4,968·6
Back pressure at maximum I.HP.	lbs. per sq. in.	10·07	6·63	15·63	13·94	7·63
" " " speed	" "	5·38	5·69	6·07	5·88	7·69
Heat carried away by the products of combustion	B.T.U.	2,394	2,427	3,052	3,179	2,884
" expended in evaporating the water	"	10,774	9,737	9,655	8,544	10,173
" lost by radiation, imperfect combustion and evaporative moisture in coal	"	735	1,739	876	1,117	420
" converted into work per minute		20,970	20,730	23,850	24,880	22,950
" taken up by the feed-water per minute		213,835	217,209	224,816	225,734	238,817

TABLE II.—BALANCE

Total heat of steam at 167·5 lbs. pressure per square inch . .	=1,228 B.T.U.
Deduct feed-temperature	61°
Thermal units taken up per lb. of steam	1,167
Lbs. of water evaporated per lb. of coal	= 9·232

Therefore 1,167 × 9·232 = 10,774 B.T.U. expended per lb. of coal in evaporating the water.

Assuming that the specific heat of air	= 0·237
and that the quantity of air required per lb. of coal . . .	= 24 lbs.
Let T = mean temperature of smoke-box gases	= 488·91° F.
and t = mean temperature of air	= 68° F.

Then the heat carried away by smoke-box gases

$$= 24\,(T-t)\,0\cdot237$$
$$= 24\,(488\cdot91-68)\,0\cdot237 = 2{,}394 \text{ B.T.U.}$$

Heat units per lb. of coal	= 13,903
Loss in smoke-box	= 2,394 B.T.U. per lb. of coal.
Available heat	11,509 " " "

Then $\frac{11{,}509}{1{,}167}$ = 9·86 lbs. of water that should have been evaporated as against 9·23 lbs. evaporated.

Therefore the heat lost by radiation and imperfect combustion &c. = 735 B.T.U. per lb. of coal.

Heat evolved per lb. of Coal.	B.T.U.	Heat expended per lb. of Coal.	B.T.U.
Calorific value of 1 lb. of coal used	13,903	Heat expended in evaporating the water	10,774
		Heat carried away by the products of combustion, lost by radiation and imperfect combustion, &c.	3,129
	13,903		13,903

SHEET, TRIAL No. I.

Heat expended in evaporating the water . . . . = 10,774 B.T.U.
Mean I.HP. = 490·6
Water evaporated per I.HP. per hour (running time) . . . 22·4 lbs.
" " " minute (running time) . . 0·373 "
Water actually evaporated per lb. of coal, inclusive of lighting up . . . . = 9·23 "
Then the heat taken up by the feed-water per minute

$$= \frac{10{,}774 \times 0{\cdot}373 \times 490{\cdot}6}{9{\cdot}23} = 213{,}835 \text{ B.T.U.}$$

Joule's equivalent . . . . = 772

The units of heat per HP. $= \frac{33{\cdot}000}{772} = 42{\cdot}75$

Then the heat turned into work per minute

$$= \text{the mean I.HP.} \times 42{\cdot}75 = 490{\cdot}6 \times 42{\cdot}75 = 20{,}970 \text{ B.T.U.}$$

Efficiency of the engine

$$= 100 \times \frac{20{,}970}{213{,}835} = 9{\cdot}8 \text{ per cent.,}$$

" " boiler $= 100 \times \frac{10{,}774}{13{,}903} = 77{\cdot}5$ per cent.,

" " engine and boiler combined

$$= \frac{77{\cdot}5 \times 9{\cdot}8}{100} = 7{\cdot}7 \text{ per cent.}$$

Heat evolved per lb. of Coal.	Per Cent.	Heat expended per lb. of Coal.	Per Cent.
Calorific value of 1 lb. of coal used	100·00	Heat expended in evaporating the water	77·50
		Heat carried away by the products of combustion, lost by radiation and imperfect combustion, &c.	22·50
	100·00		100·00

TABLE III.—BALANCE

Total heat of steam at 169·4 lbs. pressure per square inch . = 1,228·2 units.
Deduct feed-temperature . . . . 61·0°

Thermal units taken up per lb. of steam . . . . 1,167·2

Lbs. of water evaporated per lb. of coal . . . . = 7·32
Therefore $1,167 \cdot 2 \times 7 \cdot 32 = 8{,}544$ B.T.U. expended per lb. of coal in evaporating the water.
Assuming that the specific heat of air . . . . = 0·237
and that the quantity of air required per lb. of coal . . = 24 lbs.
Let T = mean temperature of smoke-box gases . . . . . = 627·0° F.
and t = mean temperature of air . . . . = 68° F.
Then the heat carried away by smoke-box gases

$$= 24\,(T - t)\,0 \cdot 237$$
$$= 24\,(627 \cdot 0 - 68) = 0 \cdot 237 = 3{,}179 \text{ B.T.U.}$$

Heat units per lb. of coal . . . . = 12,840
Loss in smoke-box . . . . = 3,179 B.T.U. per lb. of coal.

Available heat . . . . 9,661 " " "

Then $\dfrac{9{,}661}{1{,}167 \cdot 2} = 8 \cdot 27$ lbs. of water that should have been evaporated as against 7·32 lbs. evaporated.
Therefore the heat lost by radiation, imperfect combustion, &c. = 1,117 B.T.U. per lb. of coal.

Heat evolved per lb. of Coal.	B.T.U.	Heat expended per lb. of Coal.	B.T.U.
Calorific value of 1 lb. of coal used	12,840	Heat expended in evaporating the water	8,544
		Heat carried away by the products of combustion, lost by radiation and imperfect combustion, &c.	4,296
	12,840		12,840

SHEET, TRIAL No. IV.

Heat expended in evaporating the water . . . . =8,544 B.T.U.
Mean I.HP. . . . . = 582
Water evaporated per I.HP. per hour (running time) . . . 19·94 lbs.
" " " minute (running time) . . 0·3323 "
Water actually evaporated per lb. of coal, inclusive of lighting up . . . . = 7·32 "
Then the heat taken up by the feed-water per minute

$$= \frac{8{,}544 \times 0\cdot3323 \times 582\cdot0}{7\cdot32} = 225{,}734 \text{ B.T.U.}$$

Joule's equivalent . . . . = 772

The units of heat per HP. $\frac{33\cdot000}{772} = 42\cdot75$

Then the heat turned into work per minute

$$= \text{the mean I.HP.} \times 42\cdot75 = 582\cdot0 \times 42\cdot75 = 24{,}880 \text{ B.T.U.}$$

Efficiency of the engine

$$= 100 \, \frac{24{,}880}{225{,}734} = 11\cdot02 \text{ per cent.,}$$

" " boiler $= 100 \times \frac{8{,}544}{12{,}840} = 66\cdot54$ per cent.

" " engine and boiler combined

$$= \frac{66\cdot54 \times 11\cdot02}{100} = 7\cdot34 \text{ per cent.}$$

Heat evolved per lb. of Coal.	Per Cent.	Heat expended per lb. of Coal.	Per Cent.
Calorific value of 1 lb. of coal used	100·00	Heat expended in evaporating the water	66·54
		Heat carried away by the products of combustion, lost by radiation and imperfect combustion, &c.	33·46
	100·00		100·00

' (*Paper No. 2784.*)

"Grain Appliances at the Millwall Docks."

By FREDERIC ELIOT DUCKHAM, M. Inst. C.E.

THE foreign grain trade of the United Kingdom has, during the past forty years, increased with great rapidity. During the ten years ending 1850 the imports of grain averaged 1,022,067 tons per annum, while for the ten years ending 1890 they reached an annual average of 6,157,276 tons. The total quantity of corn and flour imported in 1893 was 8,165,796 tons, of a declared value of £51,180,371.

Upon the Millwall Dock being opened in 1868 it became a resort of timber- and grain-laden vessels. The latter trade steadily increased, and the best means of successfully dealing with it became a matter for consideration by the dock authorities. The system which was thereupon adopted comprised dolphins or stages, upon timber piling, driven at a distance from the dock-quays a little greater than the width of the vessel AA, Fig. 3, Plate 5; movable hydraulic-cranes, C, on the dolphins and on the quays fitted to work either buckets for bulk grain, or ordinary slings or hooks for general goods; and movable hoppers, H, to receive the grain from the crane-buckets, and deliver it through weighing-machines to barges, B, or to travelling bins. The latter, of say 18 tons capacity, form small granaries on wheels, to be taken in any required number alongside any ship, and to be moved anywhere for storage, or delivery of their contents. Roofed depots are provided in which these bins may be placed, in such a manner that any one may be unloaded without being moved, its contents sacked, weighed and delivered to railway trucks, vans, &c. Lines of railway are so arranged that deliveries may be similarly made to barges. Granaries are also provided for the storage of that portion of the grain remaining with the Company for warehousing.

The dolphins, Fig. 3, vary between 120 feet and 300 feet in length and are 12 feet wide, being constructed of fir piles 14 inches square, driven 10 feet or 12 feet into the bottom of the dock, and well bolted and braced. They are placed parallel with the quay

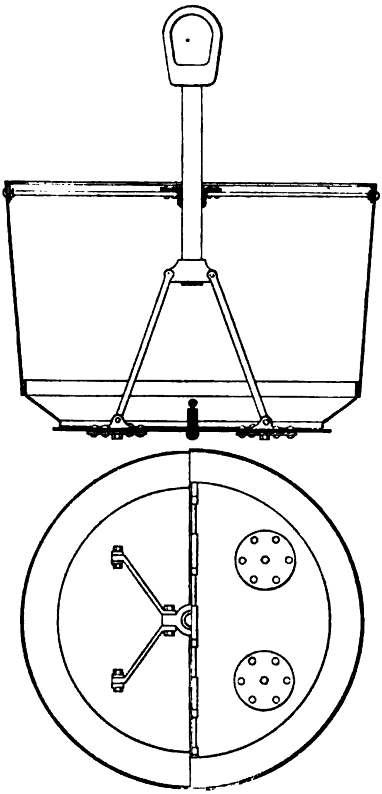
at a clear distance of 40 feet from it. Upon both the dolphin and the quay a line of railway is laid of 7-foot 6-inch gauge, that on the dolphin having heavy flange-section rails, bolted down to oak longitudinal sleepers, and that on the quay double-head rails, one of which is anchored to the quay-wall, and the other to a specially-formed bed of concrete. The dolphins are connected with the quay only by a movable gangway. On the quay there are also three lines of railway of ordinary 4-foot $8\frac{1}{2}$-inch gauge, with numerous turnouts, hydraulic capstans and leads.

The hydraulic cranes, C, are chiefly of 35 cwt. capacity: those of recent construction lift 2 tons, have a radius of 31 feet 6 inches, a lift of 60 feet, and a clear height of 50 feet from the rail-level to the centre of the jib-head sheave. The central pillar is designed as a latticed box-girder, and contains the hoisting cylinder, to which the hydraulic pressure is conveyed through a gland and waterway in the centre of the foot-step. The cranes are provided with the usual turning gear. Hydraulic pressure is supplied to the cranes by a length of $1\frac{1}{2}$-inch wrought-iron tube, telescoping at one end into a 3-inch cast-iron pipe, fixed on the bed of the crane, and having connection with the working valves. The other end of the telescopic pipe is connected with a vertical bend capable of being attached to a branch of the hydraulic main at 9-foot intervals along the dolphin or dock-quay. The waste water is returned direct to the dock, whence the hydraulic engines procure their supply. These cranes are fitted with a second chain and gear for working Priestman grab-buckets, and they have also an auxiliary cylinder or jigger, for lifting sacks, packages, &c., of less than 10 cwt. in weight. The latter are worked by a lad at the hatchway holding a line attached to the jigger-valve.

The grain tubs are of two kinds, that shown in *Figs. 1* being filled by hand, usually by six men working round it, but empties itself automatically. It is remarkable for its extreme lightness compared with its capacity, that carrying 60 bushels, or nearly 3 cubic yards, weighing but 5 cwt. Its circular bottom is divided into two parts, which are hinged to a bulb-iron bar across a lower diameter. The upper portion or shell is of $\frac{3}{16}$-inch Landore-Siemens steel, with $1\frac{3}{4}$-inch L-iron rim inside the upper edge. The lower edge is contracted for 6 inches, the lower diameter being reduced to about 1 foot less than that of the main part of the shell. The lower rim is turned, trimmed, and hooped to provide a seating for the hinged bottom. The bucket is suspended by a central rod, or preferably by a piece of $3\frac{1}{2}$-inch wrought-iron tubing passing through a suitable guide, having a suspending eye

at the top and an attachment below, by four connecting-rods, with the two doors forming the tub bottom. When in suspension, the central rod conveys the sustaining power to these doors, the bucket shell rests upon them and makes a grain-tight joint at the bottom of the tub. There is evidently no stress on the bucket sides beyond the outward pressure of the grain. The tub is emptied by being placed by the crane on an aperture on the hopper, having a seating of clear diameter a few inches greater than the contracted diameter of the tub bottom, while the crane continues lowering after the bucket shell is at rest, the doors open and the grain falls out. The doors are closed by the crane in lifting the tub off its seat, and are kept closed thereby during suspension. The Priestman grab-bucket, which is also used, requires two crane-chains, and weighs about 18 cwt. per 35-bushel skip, but it possesses the power of filling, as well as of emptying itself. Each bucket possesses, under the varying circumstances, advantages peculiar to itself. As a rule, where a large bulk has to be worked, the Priestman gear is used, but where the cargo is mixed and divided by mats, or goods in packages, &c., are stowed with the grain, the "bottomless" tub is employed.

Figs. 1.



Scale, ¼ inch = 1 foot.

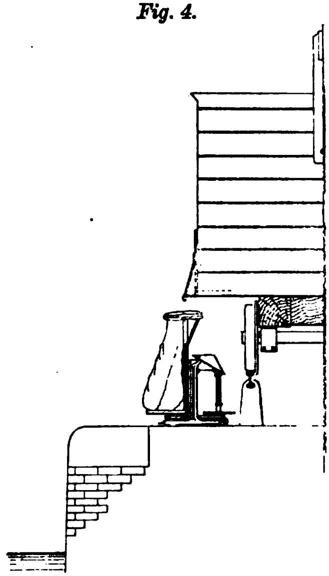
Either can, however, at any time be disconnected and the crane employed for lifting other goods by slings or otherwise without delaying the discharge of the vessel.

The hopper, Fig. 2, and H, Fig. 3, Plate 5, travels on the 7-foot 6-inch gauge railway. It has a length of 13 feet 9 inches, a width of 9 feet 9 inches, and is 18 feet high above the level of rails. It is built of wood, the upper portion being a receptacle for the grain

from the tubs. It is closed on four sides, and the top has an aperture with a seating of hard wood for the bottom-opening tubs, and a raised funnel-shaped collar to direct the inflow of the grain from the Priestman grab. In the bottom of the hopper-receiver are outlets, 9 inches square, closed by sliding doors of $\frac{1}{8}$-inch wrought-iron plate, each controlled by a regulating lever. Each hopper has ten outlets, five on each side, that it may deliver, as circumstances may require, either towards the shore or towards the dock.

To conform with the custom of the corn trade of London, and to enable grain to be delivered at times into 4-bushel sacks, the weighing-machines are of that capacity, and are placed upon a floor 7 feet above the rail-level. The weighing-machine itself resembles the ordinary sack weighing-machine, but it is fitted with a wooden box 1 foot 10 inches wide, 3 feet deep, rectangular in plan and front elevation. The bottom and a portion of the top, however, slope towards the front. There is an opening 11 inches square at the top to receive the grain from a corresponding hopper-outlet, an adjacent opening to enable the weigher to adjust the quantity if necessary, and a sliding door in the front which is lifted to allow the weighed grain to escape. Outside the hopper, in front of the weighing-machines, there is a platform for the weigher, and when grain is being delivered into barges, funnels and tubes of light sheet-steel are placed to receive it from the weighing-machines, and convey it into sacks on the barge's gunwale, or shoot it loose into the hold. If the grain is landed by means of a hopper on shore, it is delivered from the weighing-machines direct into the travelling bins.

Fig. 4.



The travelling bins, *Fig. 4*, are large plainly constructed box-wagons, 16 feet by 8 feet by 6 feet 3 inches high internally. The under-frames are of pitch-pine, and the floors and sides are of yellow deal, ploughed and iron-tongued. The four wheels are of wrought-iron with steel tyres 2 feet 3 inches in diameter on 4-inch axles, which revolve in plain cast-iron pedestals. A tarpaulin cover

is fixed on a central pole, supported by stanchions at each end of the bin, which, with the tarpaulin and ridge-pole, oscillate clear of the top of the bin when required, as, for instance, when the bins are receiving corn direct from the cranes. The floor of the bin is flat, and there are ten steel outlet-doors lifting in grooves along each side of the bin. The deliveries from the bins are usually made upon lines of railway sufficiently raised to allow a weighing-machine with its sack to be placed under the bin outlets. The flow of the grain is directed into the sacks by a hood fixed by thumb-screws in front of outlets in the bin side, and having a sliding valve 6 inches square at its aperture, to regulate the discharge into the sacks. The sack is in each case supported and held open by being doubled at its mouth over a semi-circular crutch fixed on the scale top.

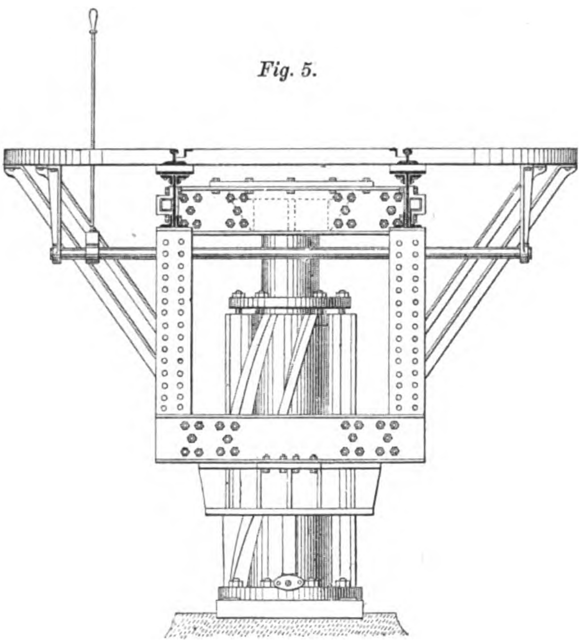
The rails are of the ordinary 75-lb. DH section, but high chairs raise the line 21 inches above the sleeper level, a total clear space of 4 feet 3 inches between the outlet and the ground level being thus provided. To reach these high-level lines at the depôt the approach sidings are on inclines, but as these were inadmissible at some places where the high-level lines were required along a jetty, close to and at right angles with the main line, lifting turn-tables, *Fig. 5*, are provided. The lifting-press is cast with two external spiral grooves, and the table has two deep girders attached below to a collar encircling the cylinder and having a roller in each of the two spiral grooves. The cylinder contains a ram 14 inches in diameter with a stroke of 3 feet. The operation of lifting, therefore, also turns the table and its load in the direction required. There are locking bolts for keeping the table steady in its upper position when the bin is being taken off or on.

The grain depôt at Millwall Docks contains 10 miles of railway sidings, and one hundred and forty sets of points and crossings, 5½ acres of the area is covered by corrugated-iron roofing in spans chiefly of 44 feet by 211 feet. There are here seventy-seven lines of rails on high chairs, giving storage-room for eight hundred bins under cover, and allowing each to be free for delivering its grain without being moved. The lines are placed with their dead ends towards an ordinary railway-platform 15 feet wide by 350 yards long. In front of the platform is a double line of railway, with frequent turn-outs, and a pitched road for vans and carts. There are moreover docks for loading railway-trucks on the opposite side of the shed, and abundant store sidings for empty wagons.

To accommodate that portion of the grain which remains at the docks longer than ten days, that is to say, the period included in the

landing charges, the Company has a number of warehouses of one or more floors. One of these differs in many points from buildings of the granary class formerly constructed. It is built of brick on foundations and basement-walls carried up from the gravel 25 feet to the quay-level in cement-concrete. It measures 150 feet by 90 feet by 81 feet from the basement to the beam of roof, and is situated 50 feet from the dock-quay. It is divided in plan into four equal sections by a transverse and a longitudinal party-wall, and has nine similar floors in each section. The roof and upper floor

Fig. 5.

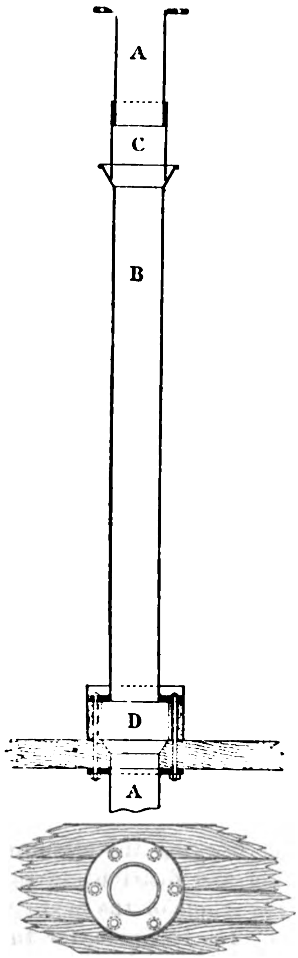


Scale, ¼ inch = 1 foot.

is partly occupied by the hydraulic-engine working the elevator, and by the hoppers and pipes for receiving and distributing the grain; the remaining portion of it and the whole of the next six floors are divided into bins, each of about 150 feet area, for the storage of grain. The ground floor is at the level of the floors of railway-wagons and vans, and is chiefly used to receive the grain from the upper floors and weigh it for delivery. The basement is available for ordinary merchandise except the space occupied by the elevator foot and its hopper. Each section of the building has its own elevator.

For housing the grain in this building, the travelling bin in which the grain has been temporarily stored is brought on rails alongside the desired section, where an adjustable shoot is hinged to project from the wall and to lead from under the binside into a commodious hopper in the basement. The bin doors are opened, and, assisted by a little trimming, the grain flows down the shoot to the hopper, whence it is lifted by the elevator about 120 feet to a small hopper in the elevator tower. From this it flows through one of two wrought steel pipes to one of two hoppers situated in the granary roof. Each of these is in the centre of twelve or fourteen shoots radiating from it and connected with the same number of pipes passing vertically through the floors of the building. The connection between the hopper and the pipes is made by a steel-plate funnel with a bent outlet, mounted to rotate on a vertical axis under the hopper, so that the flow of the grain may be directed to and be connected with either pipe. One of these vertical pipes and fittings, *Figs. 6*, is provided for each bin on each floor. They consist of a short length of pipe, A, flanged at its upper end, mounted vertically above the bell-mouthed end of another pipe, B, 6 feet long, having a flange corresponding with that of the pipe A of the next floor below. Between the lower end of the pipe A and the bell-mouth there is a gap of 6 inches, opened and closed by the sleeve C. The lower end of the pipe is kept 5 inches above the floor by distance-pieces threaded on the bolts, by which the flanges are connected. This space is also ordinarily closed by a metal sleeve D, sliding upwards on the flange of the pipe B. To admit the grain into any floor, the sleeve C in that floor is raised by lines

Figs. 6.



Scale, 1 inch = 1 foot.

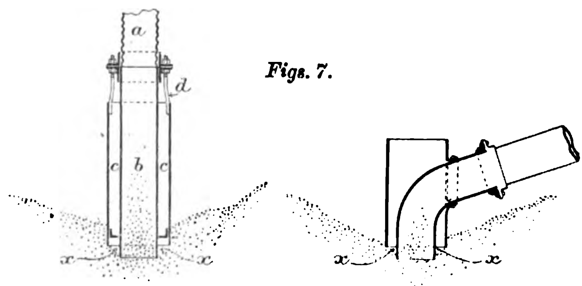
passing over pulleys, and a metal cap shaped like a Canton hat is inserted, upon which the grain falls, flowing off it with such equality as to require very little trimming to fill its bin. When the grain is to be sent away, the sleeve D is raised by means of a lever, and the grain flows down to a hopper suspended in the ground floor under the end of each series of vertical pipes. These hoppers are of about 20 bushels capacity, and have two outlets with sliding doors to regulate the discharge to two machines, where sacks, automatically held open, receive the grain for weighing, and are tied up and delivered.

These appliances have been in successful work at Millwall Docks since 1879; but like other methods of discharging grain from ships they possessed the disadvantage that the tubs lifted by the cranes cannot be brought outside the space immediately below the hatch ways; the remainder of the cargoes has to be brought to that place; this is usually accomplished by men moving the grain along with shovels. Grain stowed in bunkers and other confined spaces cannot be reached by cranes or ordinary elevators. The hatches cannot be kept open during wet weather without damage to the grain, and so the discharge of cargo is often stopped. Appliances of ordinary type entail, even with the most careful manipulation, the spilling and damage of a quantity of the grain. There is also always danger where lifting gear is used; several serious and some fatal accidents have occurred by breakage of crane-chains and similar tackle, though every precaution is taken to render the gear safe.

Some sixteen years ago the Author designed a dredger for the Millwall Dock Company. It raises the spoil by an ordinary bucket-ladder, and deposits it into a pair of tanks on board, holding about 200 tons. When brought to its place of discharge, the tanks are closed with the exception of pipes for admitting compressed air, and outlet-pipes through which the mud is forced by the air on to land 200 yards distant. The discharge occupies about thirty minutes. The success of this process suggested the use of air for the improved discharging of grain-laden ships, and the Author set himself to solve the problem of its efficient application. It was found, at an early stage of the Author's experiments, that air under partial vacuum, setting up an indraft or suction through the conveying pipes, was more applicable to the discharge of ships' cargoes than air under pressure. It was necessary to maintain a regular flow of grain through the pipes from the ship into the vacuum-chamber, to separate the air from the solid particles carried by it, and to extract the grain from the chamber without reducing the

vacuum, or interfering with the operation of the apparatus. It was found that a certain portion of air under atmospheric conditions was required to efficiently convey each volume of grain; when this portion was greater, the machine did less than its proper amount of work, and when less, the pipes became choked. The device finally adopted to regulate the proper working ratio of air to grain, is shown in *Figs. 7*. A flexible pipe, *a*, leading from the ship to the vacuum-chamber, terminates in an inlet-nozzle, *b*, surrounding which there is a sleeve, *cc*, of such diameter as to leave an annular passage between it and the nozzle of the same sectional area as that of the interior of the nozzle itself. By the screwed rods, *d*, the height of the sleeve above the mouth of the nozzle is altered according to the characteristics of various kinds of grain, the available degree of vacuum, &c. Regardless of the varying depth of immersion and other disturbing conditions, therefore, a regular

Figs. 7.



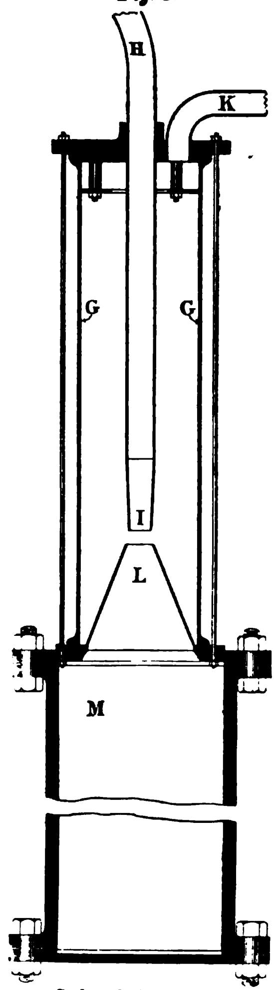
Scale, ¼ inch = 1 foot.

supply of air is drawn down the sleeve. There can never be a greater body of grain to resist its progress towards the nozzle than that marked *xx*, which is carried on with the air while the surrounding grain continually flows down to refill the vacated space, to be in turn carried up the nozzle. A wire grid or muzzle covers the mouth of the inlet-pipes when they are worked near the mats and similar divisions between different bulks of grain. The nozzle is made in various shapes, such as the bent form shown in *Figs. 7* for use between decks and in similar confined spaces.

The separation of the air from the grain was not difficult. In its imported condition, however, grain always contains a quantity of dust, husk and foreign matter, and during the early use of the machine, the exhaust air carried off some of the dust and lighter particles, with the result that, although the value of the grain was increased, its weight was diminished. Merchants who sold by weight upon a sample from the ship, objected to the use of a

machine, which, though it improved the quality of the grain, deprived them of a small part of its weight. The improved condition of the grain had therefore to be sacrificed to the maintenance of the shipped weight, and so it became necessary to find some means of weighing and delivering the grain in the same condition as to dirt and dust as it arrived in the ship. Several methods were tried, including those employed in flour-mills, &c., but with unsatisfactory results. In the course of the Author's experiments a glass vessel was used, so that the action of the machine under various conditions might be seen. The arrangement is shown in *Fig. 8*, where GG is the glass vessel, H a flexible pipe leading from the dusty material experimented upon, and terminating in the adjustable nozzle, I, a pipe K leading to the exhauster, L a funnel with its rim fitted air-tight in the closed chamber M. When in operation the partial vacuum of, say, 10 inches mercury, drew grain-laden air in through the pipe H, at a speed of about 35 feet per second, imparting to the solid particles such momentum that they were projected across the gap between the nozzle and the funnel into the comparatively still chamber M. But the air that had conveyed them was unable to penetrate or displace the somewhat denser air in the chamber M, so it is drawn off to the exhauster through the pipe K. No loss whatever could be discovered by the most careful weighing of a bushel of dusty barley before and after being passed through the apparatus. A loss of but $\frac{1}{4}$ oz. was found in 14 lbs. of fine light dust. This apparatus on a larger scale was therefore added to the machine and a by-pass provided by which the dirt deposited in the closed chamber could be returned to and mixed with the grain in the vacuum-chamber. More recently, however, the disadvantage of this procedure has

Fig. 8.

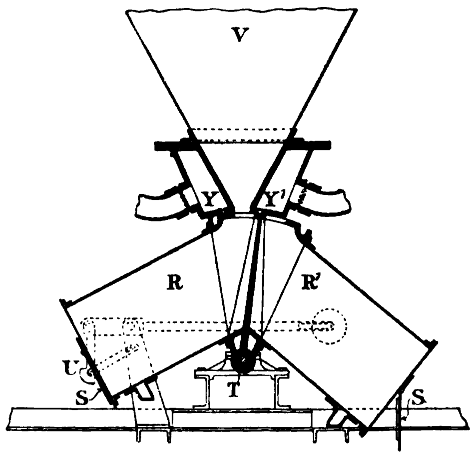


Scale, 1 inch = 1 foot.

been recognised, and instructions are often received to keep impurities separate, and deliver the grain in its improved condition, which in some instances is represented by an increased value of several shillings per quarter.

The air-lock by which the grain discharges itself from the vacuum-chamber is shown in *Fig. 9*. It is a twin box, R R^1, mounted to rock on the trunnion T. Its upper side is machined to a segment of a circle with T as its centre, and on this surface each box has its own oblong port for the admission of the grain. At the lower end of each box is an outlet closed at times by the flap-door S. To the lower end of the vacuum-chamber, V, is fixed a cast-iron outlet machined to make a practically air-tight joint

Fig. 9.



Scale, ¼ inch = 1 foot.

with the segmental part of the rocking-box. The outlet from the vacuum-chamber has one oblong port corresponding with that in either box. With the box in the position shown in the *Fig.*, the left-hand compartment, R, is under the same pressure as the vacuum-chamber, from which it would be receiving grain, while the outlet flap S would be kept closed by atmospheric pressure. When this compartment has received its full load it tips over and brings the right-hand compartment, R^1, into the loading position, the partial vacuum being broken and the grain discharging itself through the flap-door. It was found that some detent mechanism was desirable to prevent the box rocking with so small a load as might lead to its sticking halfway, and also that with the vacuum-

chamber under vacuum and the box filled with air under atmospheric conditions, the downward stream of grain through the port was retarded by the upward pressure of the expanding air which the box contained. To meet these difficulties the two auxiliary ports, Y Y[1], were added to the outlet and by means of a by-pass are kept under the same vacuum as the chamber V. Trigger-gear, U, was also fitted to each end of the rocking-box to allow the loading-compartment to make a first stage of its movement unrestrained, and in doing so to bring the port of the compartment that has emptied itself into connection with the auxiliary port Y, its air being reduced to the same state as that in the vacuum chamber. The loading continues until the weight in the box is sufficient to pull off its trigger; when the second stage of its movement is completed the flap-door opens and the other box is brought to its loading position and the operation repeated. The jockey-weights on the trigger steelyards are adjustable to approximately conform with any required weight of a box load of grain.

The machine as in use at Millwall Docks is shown in Figs. 10, Plate 5. To meet local requirements it is placed on a barge, the "Mark Lane," 170 feet long by 18 feet 6 inches wide. A horizontal compound surface-condensing engine, with steam-cylinders 15 inches and 28 inches in diameter with 4-foot stroke is used for exhausting. Each piston-rod is continued through the back end of its cylinder and connected direct to two air-exhausting pumps 38 inches in diameter. On the deck there are six sets of apparatus, each with its vacuum-chamber, its suction-hose for conveying the grain from the ship, and its rocking air-lock through which the grain discharges itself into an open hopper, and whence it is weighed and delivered either loose or into sacks. The capacity of such a machine is proportional to the power of the exhausters. The "Mark Lane" can transfer wheat from a ship to a barge at the rate of 90 tons per hour. The "Baltic," a similar machine now at work at the Royal Albert Dock, has steam cylinders 22 inches and 40 inches in diameter, and has lifted 180 tons per hour.

The amount of steam-power employed to elevate a given quantity of grain is greater with this than with the ordinary elevating machinery, but the pneumatic process removes satisfactorily the objections already referred to, and possesses many advantages over the ordinary elevator. Its suction-pipes are taken to the grain wherever it may be, even in the bunkers and cupboards, and the trimming of grain on board ship is thus almost entirely obviated. By means of convenient suspended tackle, one attendant only can easily manage a suction-pipe lifting 30 tons or 40 tons per hour. As

the conveying-pipe also occupies so small a part of the hatchway, other goods may be simultaneously unloaded by cranes or other tackle. During wet weather the hatchways are covered, room being left only for the pipe, the receiving-barge is protected by an awning, and the discharge proceeds uninterruptedly, Fig. 11, Plate 5. No grain is spilt during the process, for it is conveyed within closed conduits from the ship's hold to the barge. The dangers attending the use of ordinary hoisting-gear are avoided, and the discharge of a cargo may be commenced within a few minutes of its arrival alongside the machine. The total cost of discharge, including labour, coals, wear and tear, and other charges, is considerably less by this than by any other existing method.

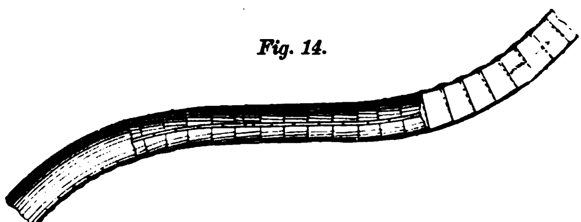
Machinery of this kind is as applicable to loading as to discharging cargoes. The loading may be effected either by raising the vacuum-chamber to a sufficient height to allow the grain to flow into the ship's hold by gravity, or it may be temporarily placed over the ship's hatch, or, preferably in the case of ocean-going vessels, the arrangement shown by Figs. 12, Plate 5, may be adopted. In it the vacuum-chamber is placed as low as it conveniently can be on board the elevator-barge, and the oscillating air-lock is enclosed, and discharges its contents into the chamber O, to which air under pressure is admitted through the pipe N, and the grain is expelled through the pipe P into the ship's hold. A great advantage of this arrangement is that the grain is not simply dropped down the hatchway, but is carried by the pipe to any part of the ship, and there deposited quietly without trimming. Where it is required to weigh the grain during the operation of shipment, weighing machinery is inserted between the vacuum-chamber and the chamber O, and a second air-lock employed. There are other adaptations and combinations of the process for lifting and conveying any grain-like material afloat or on shore, and for transfer direct between ships and granaries, such as that shown in Fig. 13, Plate 5. Steam-barges fitted with tanks to accommodate 800 tons or 1,000 tons of grain may empty themselves by air-pressure produced by their own propelling-engines. The limits of the capabilities of this process have not yet been reached, but wheat has been transmitted 800 feet including a lift of 80 feet.

The beneficial effects upon grain worked by the pneumatic process arise chiefly from the aerating and brightening of the grain in passing through the pipes; but, in addition to this, the flow of exhaust air may be arranged, when required, to carry off much of the light husk and dust. This process has proved so successful that, over and above the ordinary operation of discharging cargoes,

merchants often send their grain to the "Mark Lane" to be passed through it. The consequent increase in the value of the grain undergoing this process is considerable.

Great difficulty existed in obtaining flexible pipes to withstand the wear and tear of the grain passing so rapidly through them. Ordinary suction-hose with embedded steel-wire, lined with a composition of rubber, used as stencil masks in the sand-blast process, was the best obtainable, but was soon worn through. It was, however, found that satisfactory results could be obtained from rigid steel pipes. The Author thereupon adopted the combination shown by *Fig. 14*, in which a number of truncated cones of plate steel are strung together by external tapes in such a way

Fig. 14.



Scale, ½ inch = 1 foot.

that the smaller end of one cone enters about ½ inch into the larger end of the next. The steel rings resist wear by friction of the grain, and, being enveloped by ordinary rubber hose, are perfectly air-tight. The combination is so flexible that a 6-foot length, 8 inches diameter, may be bent through 90°. These have now been some time in use, and answer the purpose admirably.

The pneumatic machinery described in the Paper has been constructed by the East-Ferry Road Engineering Works Company, Millwall, under licence from the Author.

The Paper is accompanied by drawings, tracings, a lithograph and a photograph, from which Plate 5 and the *Figs.* in the text have been prepared.

(*Paper No. 2811.*)

"The Caisson at the North Pier-head, Madras Harbour."

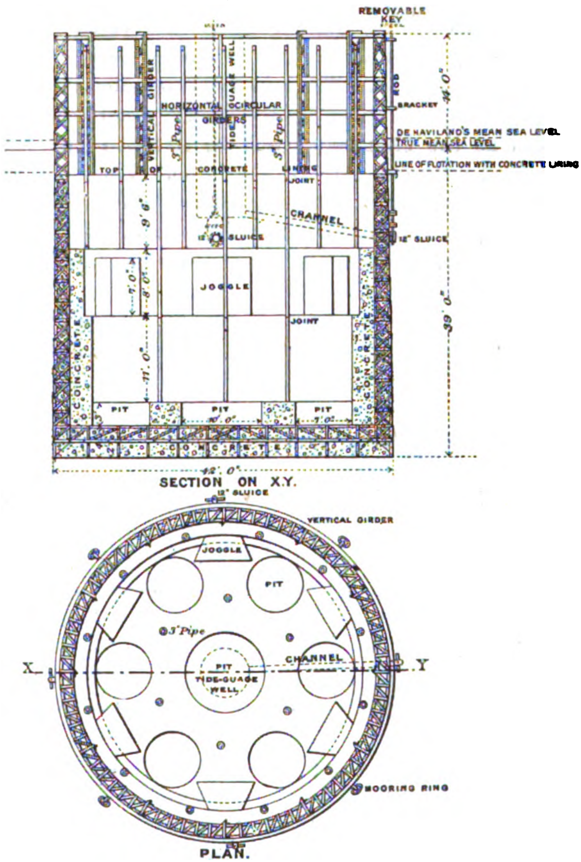
By Robert William Thompson, Assoc. M. Inst. C.E.

In the restoration of the Madras Harbour the pier-heads were originally designed to be 34 feet wide, and to be founded on a rubble base 34 feet below the De Havilland mean sea-level, the piers being 24 feet wide and founded 22 feet below that level. They terminated in an outward curve at the old pier-heads into which they were to be bonded as far as practicable. In February, 1890, it was determined to modify this design, and to found the pier-heads 18 feet lower than the piers—or 40 feet below the De Havilland mean sea-level, and to construct their ends of cylindrical monoliths of concrete, of a diameter equal to the width of the pier-heads at the footings, founded at the same level, and rising to a height of 6 feet above the level of the piers, that of the concrete capping which it was intended to place upon them. It was further determined that the monoliths should be made in the dry, instead of by discharging concrete into the sea.

For each pier-head a water-tight iron caisson, *Figs. 1*, was therefore provided, of 42 feet and 41 feet 5½ inches outside diameter at the base and top respectively, and 53 feet high. The bottom and sides were covered by plating ¼-inch thick. The sides were constructed in fourteen tiers or bands consisting each of eight plates 16 feet 6 inches long by 4 feet high. Both the bottom and sides were strengthened with ribs of lattice-girders. Across the bottom, each one along the centre of a row of plates, ten girders, 2 feet high, were placed 3 feet $9\frac{3}{16}$ inches apart, from centre to centre. The sides were supported by fifteen circular girders, varying in depth between 1 foot 9 inches at the bottom, and 1 foot 6 inches at the top, placed horizontally; and twelve vertical girders, varying in depth between 2 feet at the bottom, and 1 foot 9 inches at the top. The vertical girders were set at equal distances apart; they are continuous only in the flange nearest the centre of the caisson, which consists of an angle-

iron 3 inches by 3 inches by $\frac{3}{8}$ inch in two lengths, connected by a bar cover riveted to them, the joint being 23 feet 10 inches from the bottom of the caisson. The other portions are in sections suiting the distances between the horizontal girders, and are let in between them and riveted to the side plating by $\frac{3}{4}$-inch rivets

Figs. 1.



Scale, $\frac{1}{24}$ inch = 1 foot.

of 5 inches pitch, the tiers of side-plates being riveted together by $\frac{5}{8}$-inch rivets of $2\frac{1}{2}$ inches pitch. The plating is laid telescopically, so that each tier is $\frac{1}{2}$ inch smaller in diameter than the one immediately below it.

The caisson was furnished with eight mooring-rings in two tiers 19 feet 10 inches and 43 feet 8 inches respectively, from

the bottom. It was also furnished with four 12-inch sluice-valves fitted to the outside of the eighth tier of side-plates, 27 feet 7 inches from the bottom. Eighteen 3-inch wrought-iron pipes riveted over 3-inch holes in the bottom were also provided, twelve being placed at the angles of a regular polygon of twelve sides 34 feet 6 inches in diameter, and six at the angles of a hexagon 18 feet in diameter, the centres of both polygons coinciding with that of the caisson. The pipes are for the purpose of grouting the rubble base beneath the caisson with liquid cement. They had screw ends and were built to a height of 50 feet in three lengths. Their height could not be reduced as the base could not be grouted till the caisson had been filled with concrete, or nearly so. They had also to be built while the caisson was afloat. Great difficulty was experienced in getting to the tops of these slender pipes to add new lengths, and in securing them as they were built; for they were too slender to support themselves as the caisson rolled and pitched. Bracing had therefore to be inserted between them and the sides of the caisson which hindered the lowering of materials and plant. Great anxiety was felt lest a fracture should occur below the water-line, the consequence of which would, in all probability, have been the sinking of the caisson.

The caisson for the north pier-head was built by Messrs. P. & W. Maclellan, Limited, Clutha Works, Glasgow, and that for the south pier-head by the Teeside Iron and Engine Works Co., Limited, Middlesbrough. They are similar, except that the former has an additional bracing of three transverse bottom lattice-girders 2 feet deep, riveted over the tops of the other ten and at right angles to them. They are placed one at the centre and the other two 11 feet from it on each side.

The north caisson was received in its component sections, and was built in a small temporary dock, about 50 feet square, constructed at a shelving part of the sandy beach inside Madras Harbour. The sides of this dock were composed of old block-frames or moulds in which the blocks required for the piers and wave-breakers had been made. These measured 14 feet by 6 feet, 10 feet by 6 feet, and 9 feet by 6 feet; the height being in all cases 6 feet, the depth of the dock. These frames were sunk in position and bolted to each other, the area enclosed by them being excavated by hand, to bring the floor about 4 feet below mean sea-level. The two sides of the dock, which were at right angles to the line of the beach, were also prolonged into it by block-frames, except at the ends where the beach ran low; special frames 8 feet

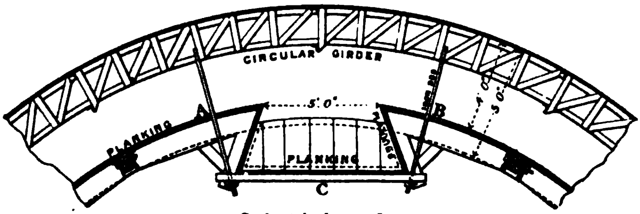
high being made for this portion. These prolongations retained the sand on each side, and so kept the outlet clear when the partially built caisson was being launched. A second row of block-frames was run between these prolongations at right angles to them, and as close to the sea as possible, the space between this row and that forming the adjacent side of the dock being excavated to the same level as the floor of the dock. This was done only a short time before launching, and afforded a cutting, for a part of its length, of the channel in which the caisson was launched. The second row of block-frames formed a screen to exclude sand from the sea. As the block-frames were set in position they were filled with stones and sand. A small sump was sunk at one corner of the dock into which the suction-pipe of a No. 7 pulsometer was introduced, the dock being thus kept sufficiently dry. A railway siding of 5-foot 6-inch gauge was laid from an adjacent line to the dock to provide communication with the workshop yard, and a powerful hand-crane on wheels was placed at the end of this siding to transfer the material from the trucks to the dock.

Inside the dock a temporary staging about 3½ feet high was constructed of sleepers and rails, and so arranged that the seams of the bottom of the caisson which were to be riveted were left accessible to the riveters. The caisson was built to a height of two tiers of the side plating, about 7 feet 9 inches, on this staging. It was then lowered and rested on the bed of the dock. This was accomplished by admitting water into the dock through a pipe till the caisson, which at that stage drew only about 6 inches of water, floated off the staging. The rails and sleepers were then drawn from under it and the water was pumped out of the dock when the caisson rested on the floor. Water was subsequently let into the caisson and pumping of the dock was discontinued, as the riveting had reached above the level to which the water could rise within it. The riveters on the outside worked on hook trays, 6½ feet long by 3 feet wide, which were hung on the side plating; while those inside were accommodated on planks resting on the circular girders. The caisson was thus built to a height of six plates, or 23 feet, when it weighed about 50 tons, and drew about 15 inches of water. The barriers of block-frames, which lay between it and the sea were then removed and the sand beyond the outside barrier excavated. A steam launch then took the caisson in tow, while a force of coolies pushed it from behind, and the caisson was successfully launched. The caisson was towed to the elbow bend of the north pier and moored within a few feet

of it, and the work of charging it with concrete was at once commenced. A solid floor of concrete 4 feet thick was first deposited, causing the caisson to draw 10 feet of water, and a thickness of 3 feet was then added, seven circular pits, *Figs. 1*, being left. The caisson was thus lowered an additional 5 feet, drawing 15 feet of water, and standing 8 feet out of the water. The building up of the sides was then proceeded with, as well as the insertion and fixing of the wooden framing for lining the sides with concrete.

The circular pits in the concrete floor were made by wooden core-frames; that for the 10-foot pit being in six, and those for the 7-foot pits in four pieces. The concrete lining was also built by means of wooden frames, that for the lower portion, 5 feet thick, being in ten pieces. These frames were only 5 feet 6 inches in height, and were used twice in the 11 feet of height of this portion of the lining; being lifted on to wooden putlogs

Fig. 2.



Scale, ⅛ inch = 1 foot.

or brackets built and anchored into the lower half when the upper half had to be built. In the framing required for building the second portion, 4 feet thick, provision had to be made for six dovetailed joggles, *Fig. 2.* These are 3 feet thick and overhang the lower portion of the concrete lining by 2 feet. The parts A and B were distinct, and were placed 5 feet apart; the back planking C was then set into position between them, and boards for the floor placed with one end resting on a waling-piece at the bottom of the back planking and the other on the lower portion of the lining. The frames were held upright by iron rods with a screw and nut at one end and a hook at the other; the screw end being passed through the upper member of the back frame and the hook fastening on one of the circular girders. The upper portion of the lining was built by fixing to the rib girders the iron sheets intended for the upper band of plating of the caisson.

When about 3 feet of the first portion of the lining had been

inserted, it became necessary to move the caisson from the berth near the pier to one farther out in the harbour, clear of the rubble base on which the pier is built, over which there was not sufficient depth of water. The concrete required for the lining was therefore taken out from the pier in boats and handed up in baskets to men standing on swing-trays hanging from the plating, who shot it down through canvas shoots wherever required; men being stationed below to receive it and work it down. The riveting was completed on the 3rd of March, and the concrete lining in five days from that date; the caisson then drew 36 feet of water. It was originally intended to make the concrete lining so that the caisson would draw 37 feet of water, allowing 3 feet between the bottom and the rubble base upon which it was to be set. It was assumed that high water at the time would rise to at least the De Havilland mean sea-level, or 40 feet above the rubble base. But the tide tables for the year showed that high water about the time would not rise higher than true mean sea-level, or 39 feet above the prepared rubble base. The height of the 4-foot portion of the concrete lining was therefore diminished by 1 foot, and that of the upper portion was also slightly reduced.

The rubble base upon which the caisson was to be set was carefully examined and was made with a slight inclination to tilt the caisson slightly inwards towards the blockwork of the pier-head and the wave-breakers which would lean against it. The approach to the spot was also examined. The caisson had previously been brought up and berthed close to the pier-head, not far from its final position. Hawsers were then attached, one leading to the North pier-head, one to the old North pier-head, one to the South pier-head, one to a boat anchored in a suitable position a little outside the harbour, and one to the steam-launch. A system of signals having been arranged, the caisson was released from her berth and the hauling began. It was a calm morning and no hitch occurred. Four men had been stationed on swing-trays at the keys of the four 12-inch sluices already mentioned. The instant the caisson was in position these were opened and the caisson almost immediately grounded. About 500 tons of water were then admitted. This weight left about 400 tons to keep the caisson in position, but as an additional precaution, a stout hawser was passed round it and the two ends made fast to the pier-head.

One cylindrical concrete block 8 feet in diameter and 8 feet high, weighing 25 tons; four cylindrical blocks 5 feet in diameter and 8 feet high, weighing 40 tons; five ordinary wave-breaker blocks

9 feet by 9 feet by 6 feet, weighing 150 tons; and nine special blocks each 9 feet by 4½ feet by 6 feet, weighing 135 tons, were then lowered through the water into the caisson. The large cylindrical block was placed in the centre pit, and the four small blocks in the four side pits nearest the pier-head; the other two pits being beyond the reach of the crane, the remaining blocks were placed upon these and each other. The water was subsequently pumped out by the pulsometer, and the concreting was proceeded with. When the work had reached to about 5 feet above the floor-level three of the wave-breaker blocks were taken out and some of the small blocks were rearranged so as to surround them with concrete. Other small blocks, 9 feet by 4½ feet by 6 feet, were inserted as the concreting proceeded and were buried in it.

The four 12-inch sluices admitted a large volume of water into the caisson in a short time, in order to sink it quickly as soon as it arrived in position. After the concrete had been filled in, these sluices were detached. The filling was not carried up solid to the top. A well, 6 feet in diameter and 23 feet deep, was left in the centre for a tide-gauge, and a channel, 1 foot square in section, was arranged between the bottom of this well and the sluice hole opening into the harbour. It is intended to erect a small lighthouse, 21 feet high, upon this cylinder of concrete, to light the entrance to the harbour. The lighthouse is to be divided by a floor into two chambers, the lower being a tide-gauge room and the upper a lamp service-room.

The time occupied by the work was six months: the riveting together of the caisson having commenced in October 1893, and the filling of it with concrete at the pier-head being completed on the 31st of March, 1894.

The last or upper band of iron plating was not put on, and the concreting is therefore short of the ultimate intended height by 4 feet. The surface as left at present is not level throughout, but has been stepped to receive the remaining concrete to be added later.

The Paper is accompanied by two drawings, from which the *Figs.* in the text have been prepared.

(*Paper No. 2877.*)

"Repairs to a Submerged Main, Toronto Waterworks."

By ALAN MACDOUGALL, M. Inst. C.E.

THE city of Toronto is situated on the north side of Lake Ontario, about 40 miles from its head. It possesses a fine harbour about 2 miles long by 2 miles wide, entered from the west end, and bounded on the south by a large deposit of sand which was originally a peninsula. About forty years ago the lake washed through the eastern neck of the peninsula, forming a large gap and creating what is now known as "the island." The opening of the sand bar has had an important influence on the health of the city, as a current is constantly passing through the bay, changing the water and in some measure purifying its now sadly polluted condition. Since the first drain was constructed the sewage of the city has been poured into the waters of the bay or harbour, and for a period of more than fifty years the decomposing organic matter has been lodged along the front of the city, filling the spaces between the wharves, polluting the water and causing nauseous odours along the lake front. The proposed trunk- or main-outfall sewer has been reported upon by several of the city engineers, as well as by a commission of eminent American engineers, during the past twenty years, but its construction does not appear to be a work of the immediate future.

In 1842 a franchise was granted to a company to construct and work a system of waterworks for twenty-one years. The supply was drawn from the bay, a short distance from the shore-line. The undertaking does not appear, however, to have been a success, for in 1850 complaints were made of the deficiency of water at fires, and in 1854 an effort was made by the city to construct waterworks. Competitive plans were received and premiums were awarded, but the matter was not pursued further. Public attention was, notwithstanding, aroused to the necessity of having a better and a safer supply, and the city council consulted Mr. Thos. C. Keefer, C.M.G., M. Inst. C.E., in 1857, who reported on several proposals. No action was, however, taken on his reports, as the city was not at that

time disposed to engage in such a large expenditure as £290,000, the amount of the estimates. Even at this date the condition of the water was bad, being drawn from the bay immediately in front of the city. In April of the preceding year, attempts were made to influence public opinion to purchase the waterworks; but, despite the public statement that the directors of the waterworks were fully sensible of the deficient supply and of the impure quality of the water, the citizens submitted to the supply for fifteen years longer. Only in the year 1872 was an act of legislature obtained enabling the city to construct a system of its own. Mr. Keefer reported in 1857 in favour of taking the water from Lake Ontario, and pumping it into a reservoir at a sufficient elevation to give a gravitation supply to the city. He suggested two sites, one about 7 miles to the east, and the other 4 miles to the west of the centre of the city. After the city received legislative powers to construct works, he was again consulted by the council before any definite conclusion was arrived at. All possible sources were examined, including some small lakes, situated about 15 miles north of the city, in the "Oak Ridges," from which it was considered a sufficient supply could be obtained by gravitation. An examination of the watershed and of the lakes showed that the expense of the scheme would be too great, and the supply of water unsatisfactory both in quality and quantity. Lake Simcoe, another source of supply by gravitation, was also investigated. This lake is situated 35 miles to the north of Toronto, and is the highest in the province, being 470 feet above Lake Ontario and 120 feet above Lake Huron. It has an area of 300 square miles and a watershed of 1,100 square miles. The water is of a fair potable quality, but not equal to that of Lake Ontario. As the conduit must have been several miles long and 200 feet under the surface of the ground, tunnelling and other expensive works would have been necessary, rendering the cost prohibitive both in the past and in the present. After considering all these possible sources, Mr. Keefer again recommended the lake as a source of supply. He enforced the recommendation by stating that great strides had been made between 1857 and 1872 in submarine engineering which had removed many hitherto existing difficulties with regard to work under water, and he further instanced the advantage of the then newly-invented flexible pipe-joint. He had also had experience, in his proposal to draw from the lake, in the case of the City of Hamilton. This, the next most important city in the province to Toronto, is situated at the west end of the lake and 40 miles distant. There he had successfully

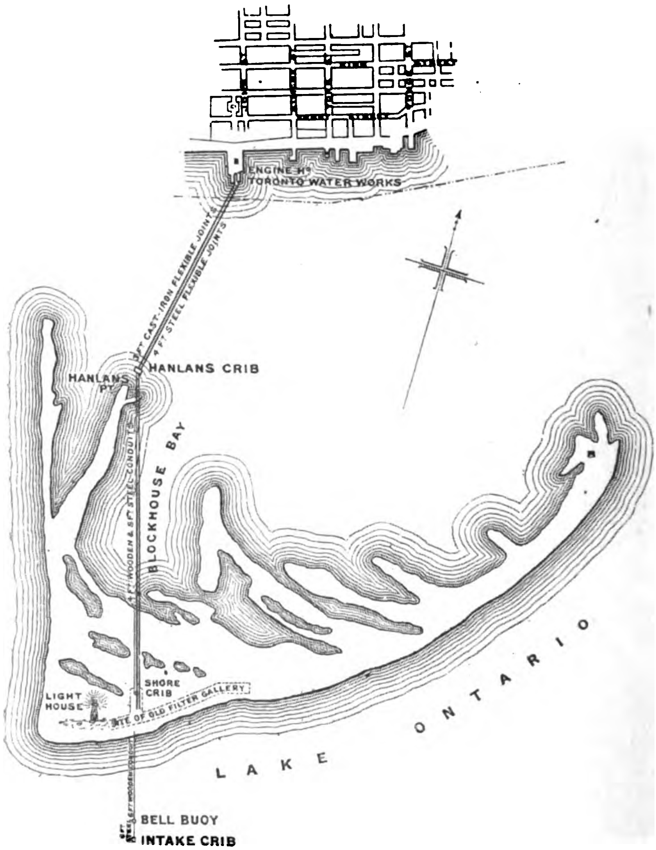
constructed a filter-basin close to the lake shore from which the water was pumped to a high-level reservoir. Associated with Mr. Keefer was Mr. E. S. Chesbrough, at that time city engineer of Chicago and engineer for the tunnel supply for the city, who endorsed his plan.

After lengthened negotiations with the company owning the waterworks, the city purchased the whole of their plant, piping, reservoirs and other works, in 1872, for the sum of £44,000 sterling. In the four following years £256,000 was expended in constructing the system which forms the basis of the present water-supply. The works commenced at a filter-gallery or basin on the south shore of the island, *Figs. 1* and *2*, situated 155 feet from the water's edge, and originally 1,000 feet long. It was extended till its final dimensions were 2,700 feet in line with the lake shore, with an arm nearly at right angles in the direction of the wooden conduit, 390 feet in length. The bottom of the gallery was 13·50 feet below zero level of the lake, the area of the water-surface was 5·64 acres, and the contents of the gallery at zero level were 13,287,337 imperial gallons. The level of the top of the conduit was 6 feet 7 inches below zero. From this filter-gallery a wooden conduit, 4 feet in diameter, was carried across the sand bars and lagoons which form the island for a distance of 6,000 feet, to a connecting crib at "Hanlan's Point." From thence a cast-iron, flexible-jointed pipe, 3 feet in diameter and 4,540 feet in length, carried the water to the pump-wells of the pumping-engines on the main land.

The anticipations of the filter-gallery were not realized, the sand being so compact that the infiltration was not sufficiently rapid. Accordingly it was necessary, in 1877, the year after pumping was commenced, to cut two channels into the lake. These were placed 500 feet apart. For the westerly channel a trench was dredged to a depth of 12 feet below zero level, with a bottom width of 20 feet, and side slopes of 2 to 1, and carried out into the lake 300 feet from the inside of the basin. The cut or trench was then filled with flat stones and small boulders, of about 6 cubic inches, to a depth varying between 9 feet at the basin and 6 feet at the lake end; over this a layer of gravel was spread about 18 inches deep, to bring the top of the filling to the level of the surrounding lake bottom. For the easterly channel a wooden conduit, of the same size and description as that across the island, was laid from the inside of the basin, through the embankment and beach, at a depth of 11 feet, for a distance of 245 feet towards the lake. A crib, 20 feet square and about 17 feet high, was

constructed over the end of the pipe. It was divided into nine spaces or pockets, all of which were filled with stone, except the centre one. This was left as a well-chamber and from it the pipes started. Another pipe of the same description extended 50 feet

Fig. 1.



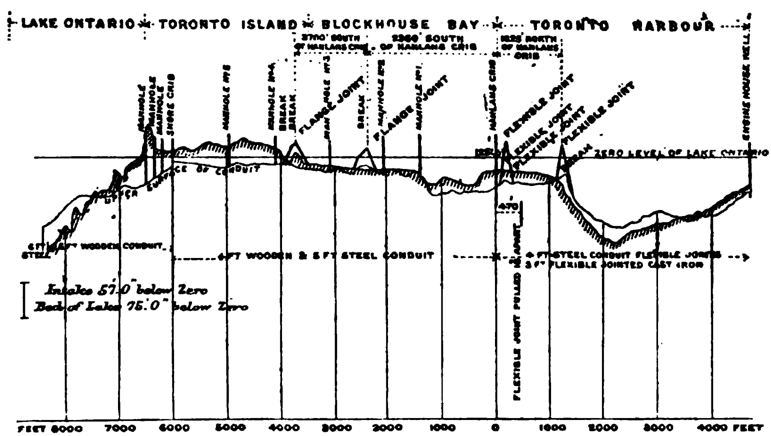
Scale, 3,600 feet = 1 inch.

GENERAL PLAN, SHOWING CONDUITS.

into the lake, and this was bored with 2-inch auger holes, 12 inches apart in each plank. The space round the crib and perforated pipe was filled with stone and gravel, and the beach restored, as in the case of the other trench. This work was completed in August, 1877.

In March of the following year it was discovered that a semicircular mound, or bar of sand, had formed in the filter-basin, opposite the pipe, which was completely choked with sand. The level of the filter-gallery was drawn down below the lake level by pumping, establishing a head sufficient to scour out some of the sand in the pipe and disperse the bar at its mouth. The next trouble appeared in December of the same year after stormy weather, when the sand filled the western channel completely, half filled the pipe in the eastern also, and further formed a sand-bar in front of the conduit 20 feet wide on the top, and 9 feet above the bottom of the basin. Several efforts were made during

Fig. 2.



Vertical Scale, 50 feet = 1 inch.
Horizontal Scale, 3,600 feet = 1 inch.

LONGITUDINAL SECTION OF PIPE-LINE.

the succeeding months to clean the sand out of the channels and maintain a supply, all of which were unavailing. The use of the filter-gallery was eventually abandoned in June, 1879.

Surveys were commenced for an extension of the conduit into the lake as soon as the filtration scheme failed, and a constant supply was obtained in 1881, by the construction of a wooden conduit 6 feet in diameter, and 2,357½ feet in length, terminating in water 25 feet deep. This work was constructed under the charge of Mr. T. J. McMinn, by whom the mode of construction and laying has been described.[1] A further extension of the conduit

[1] Proceedings of the Canadian Society of Civil Engineers, vol. ii. p. 67.

was made in 1891, when a steel pipe was laid for a length of 350 feet, terminating in 75 feet of water. The work was under the charge of Mr. W. C. Brough, a younger brother of the late Mr. Redmond Brough, who, as city engineer, superintended the laying of the first pipe across the bay. This conduit has been an unfortunate investment for the city, as ever since it was laid it has been a source of trouble.

On the 7th December, 1875, about a fortnight after the water had been let in, several portions of the 4-foot wooden conduit rose to the surface. In the following year the conduit was taken up, reconstructed and relaid. Some months after reconstruction it was pumped out, and examined by three persons who walked through its entire length and reported favourably on its condition; despite this fact, the public lost confidence in it, and the opinion became accepted that it was not water-tight. A recent examination by a diver, under the direction of Mr. E. H. Keating, M. Inst. C.E., the city engineer, has shown the conduit to be in good order. The 6-foot wooden conduit extending into the lake has been examined during the past two years, and found half full of sand in some parts and in bad condition, whilst the steel-pipe extension into deep water was found to be disjointed and dislocated on the bottom of the lake, full of sand and useless for all purposes as a conduit. The only portion which has given no trouble is the 3-foot cast-iron pipe. The laying of this was a success; recent examinations of the joints, made by divers, show the pipe to be perfectly tight and in good order.

Several years after the construction of the works, when the growth of the city demanded an increased supply, the gravitation schemes again appeared. In 1886, the late Hon. W. J. McAlpine, of New York, and Mr. Kivas Tully, of Toronto, examined the district, and prepared a report on a proposed supply from the lakes at Oak Ridges, and recommended those lakes as a source of supply. This report was presented to the city council in February, 1887, but no action was taken upon it. In the autumn of 1888, Messrs. Rudolf Hering, of New York, and Samuel Gray, of Philadelphia, MM. Inst. C.E., were engaged to report on all sources of probable supply. They examined each scheme, and reported in favour of pumping from Lake Ontario. Their recommendations were adopted by the city council in February, 1889.

The growth of the city during 1887–89 demanded an increased supply, chiefly for fire protection and manufacturing purposes. Like other large cities on the American Continent, the daily

consumption is considerably beyond that allowed to the ordinary British water-consumer. In Toronto it has averaged 100 imperial gallons per day per head of population for many years; the average daily supply for 1894 was 18,000,000 gallons for a population of a little over 220,000. To meet the increased demand, a flexible-jointed steel boiler-plate pipe, 5 feet in diameter, was, during 1890–91, laid through the island, parallel to the 4-foot wooden conduit, and connected to the shore crib in the old filter-basin and the connecting crib at Hanlan's Point; and a 4-foot flexible-jointed steel boiler-plate pipe was laid from Hanlan's Point to the pump-well in the engine-house. After these pipes were laid, the 6-foot lake supply-pipe was extended 350 feet into the lake by a steel pipe terminating at a depth of 15 feet; it had no flexible joints when originally laid, the hydraulic gradient being preserved by a series of cribwork. As soon as the water was drawn through the 5-foot pipe the 4-foot wooden conduit was closed, and the supply was delivered from Hanlan's Point through the 3-foot cast-iron and the new 4-foot steel pipes.

The steel pipes were all made in the Province of Ontario; the 4-foot pipes in Peterborough at the Central Bridge Works, the cost being £1 9*s*. 0*d*. sterling per foot, and the 5-foot pipes in Toronto by the Abell Manufacturing Co., at a cost of £2 0*s*. 7½*d*. per foot. The 6-foot pipe was made at the Central Bridge Works, and cost £3 5*s*. 7½*d*. sterling per foot. The flexible joints were constructed by Mr. W. H. Law, of the Central Bridge Works, Peterborough, and proved most successful. The joint for the 6-foot steel-pipe extension into deeper water was designed by Mr. John Williams, of the engineer staff, and was made at the Central Bridge Works, Peterborough. There are sixty-three flexible joints in the 4-foot pipe, fifteen in the 5-foot pipe, and two in the 6-foot pipe. The prices of the joints were:—For the 4-foot pipe £37, for the 5-foot pipe £43 10*s*. 8*d*., and for the 6-foot pipe £125 9*s*. 6*d*.

On Christmas Day, 1892, the 4-foot steel conduit suddenly rose to the surface at several places between the connecting crib at Hanlan's Point and the pump-house wharf. In settling down two flexible joints were exposed above the surface of the ice, one 125 feet, and the other 1,325 feet north of the connecting crib. The 5-foot pipe also rose, and left two portions exposed above the ice, each about 100 feet long, parting at two cast-iron flanged joints respectively 2,365 feet and 3,700 feet south of the connecting crib at Hanlan's Point. The accident was caused by the closing of the mouth of the 5-foot steel conduit in the shore crib

by drift-weed, which was removed daily from the face of the screen by an attendant resident on the island. He had not paid his accustomed visit on the previous day, so on Christmas Day, 1892, the screen was choked, and, pumping being continued at the pump-house, the water was drawn out and the conduit floated. This screen has been removed by Mr. Keating, and the water now flows from the lake into the well at the pump-house, where suitable screens prevent any drift weed or fish from entering the pumps. This arrangement places the screens under the control of the engineer at the pump-house. A thorough examination of the 4-foot conduit was at once made, from the connecting crib at Hanlan's Point to a point 150 feet north of the northernmost exposed joint, and resulted in the discovery of a flexible joint at a point 475 feet north of the crib which had been pulled apart, the turned zone being drawn out of the angle-bar and rings, forming a gap 22 inches wide. Further on, at 1,260 feet from the crib, a seam was found torn partly asunder, leaving an opening on the under side of the pipe 4 inches wide. An examination was made at the end of March, three months after the accident, over the entire distance between the waterworks wharf and the crib at Hanlan's Point. The sixty-three flexible joints were examined as far as practicable; some slight leakages were found, the existing lead was caulked into the joints, and in a few cases between 4 lbs. and 5 lbs. of cold lead in strips were caulked in. Only the upper half was caulked in this manner; the lower portion was not disturbed, it being ascertained that the weight of the pipe kept the joints tight. Near the waterworks the pipe was buried about 2 feet under the mud, which had to be cleared away before the joints could be reached.

The examination of the 5-foot pipe was made as the repairs on the risen portion were proceeded with; two pairs of fractured flanges were discovered at distances of 2,490 feet and 3,825 feet south of the connecting crib, in addition to the joints which had risen. The urgency of the work to be undertaken permitted of no delay, as the health of the city was endangered, and it was imperative that a supply of pure water should be available. The work of repairing the damage was carried out by the city engineer, and was placed under the immediate charge of Mr. John Williams, who pushed on the work with great energy through the cold winter weather, succeeding in covering all the breaks, and giving an almost pure supply to the city before the ice left the harbour on the 20th March. The repairs to this conduit carried on during the shortest days of the year, in day and night shifts,

in an exposed position where the workmen were subjected to continual freezing winds and where no comforts of fires were available, was a work of no mean magnitude. The vicissitudes of the situation were exciting, the ice was an uncontrollable quantity, it had formed on the bay only a day or two before the accident, and at that time was not 6 inches thick. The chances of the completion of the repairs depended on a south wind, which would in a few hours, break up the surface of the ice, and on the continuance of the frost, which could not be guaranteed, whilst the middle of March was certainly the latest date on which dependence could be placed. The winter fortunately became steady and cold; no thaw occurred and the ice formed well, being between 14 inches and 24 inches thick. The night gang excavated a sufficient quantity of sand to keep a couple of teams and sleighs working all day removing the material. The cost of this work was not abnormally high.

To the north of Hanlan's crib there was one flexible joint and a torn seam to repair in the 4-foot conduit. This fracture was the first to receive attention; the pipe was drawn westward by powerful winches placed on the ice, steel hawsers being attached to the pipe (the flexible joint allowing the conduit to move), and the dimensions of the angle of the bend were taken and a sleeve applied. The flexible joint near the crib was more difficult to manage, for a quantity of sand and stones had to be removed from below the pipe by hand-dredges and a steam-pump. It was found necessary in order to close the open joint, and bring down the one above the surface, to haul a length of 350 feet northwards to allow the joint to close. The pipe was slung on strong cables secured to heavy timbers placed on the ice, the cables being fastened to screw-jacks placed on frames built on the ice. Three pairs of heavy tongs, similar to ice-tongs, having the same curvature as the pipe, grabbed it tightly; these were fastened to baulks of timber, and when the pipe was raised from the bottom it was hauled northward. After it was adjusted and had sunk, the opening was reduced from 22 inches to 5 inches wide, and the work was completed in twenty-eight days after the accident. The north end of the pipe was left half its diameter higher than the other, and the city was supplied from this point during the period of repair, the joint being finally closed about the 18th March, two days before the ice broke up.

While the work north of the connecting crib was in progress, preparations were made to lift the 5-foot conduit in Blockhouse Bay, at points 2,365 feet and 3,700 feet south of Hanlan's crib.

Piles were driven on each side of the exposed pipe and heavy cross timbers were placed on them, cables and tongs being fixed round the pipe and attached to the cross timbers by chains and screw-jacks. The pipe was lifted high enough to allow the remaining bolts to be taken out and the broken flanges to be removed; this was completed by the 11th February. Steel sleeves were prepared, being so constructed that they would act as expansive joints as well as covers. Further fractures being found at 2,490 feet and 3,825 feet from the crib, where the cast-iron flanges were not broken off, a deep hollow sleeve was placed over the joint. Sheet lead was beaten round the fractured portion, which was covered with two thicknesses of canvas and two of cotton cloth, each covering being securely lashed to the pipe. This section was lowered into the water on the 2nd March. Work was then resumed on the northerly portion of the pipe near Hanlan's crib. A large quantity of stone having been removed from under this portion, and the sand having been hand-dredged by gangs of men working night and day, through intensely cold weather, the pipe was lowered to 3 feet 1 inch below the surface of the ice by the 19th March. The last portion of the work was closing the flexible joint in the 4-foot steel conduit, 475 feet north of the connecting crib. The south part of the sleeve was made on the angles taken from the flexible joint and was slipped over the raised portion of the pipe, which, on being lowered, was bolted into its original position. The space between the sleeve and the turned face or zone was caulked by a ring of heavy lead pipe firmly driven in, and afterwards by several strands of plaited hemp and tallow gasket. As cement could not be used in this sleeve, caulking was most carefully done, and a ring was drawn up close to the packing by eight long bolts.

The method of repairing the joints was designed by Mr. Williams. The sand was first pumped and dredged from under the pipe; then a covering of canvas was placed over the break, a strip of galvanized iron of sufficient length and width to cover the opening was sewn between two pieces of canvas and lashed round the pipe with strong rope; two thicknesses of canvas were then securely lashed on each side by six strands of rope. The steel sleeve, when ready, was placed over this without disturbing the canvas and sheet-iron covering. The sleeves were of $\frac{3}{8}$-inch steel plate, in two pieces. About 4 inches from each edge, a piece of very strong rubber hose, $1\frac{3}{4}$ inch in diameter, was sewn with copper wire through small holes drilled through the steel, about 6 inches apart; the cut ends of the rubber hose

were left projecting about $\frac{1}{4}$ inch from each edge, the two parts were bolted together with seven 1-inch bolts in each flange; solid rubber packing-pieces, $1\frac{1}{4}$ inch thick, were placed between the plates. When the bolts were drawn tight, the ends of the hose were forcibly pressed into the rubber packing-pieces, thus making a perfectly water-tight joint. The angular space between the pipe and sleeve was filled with Portland cement. For this purpose two 2-inch holes were drilled on the top of each sleeve. A pipe was screwed in and brought to the surface of the water through which the cement was poured. The cement was mixed neat, and was sufficiently moist to flow. After the space had been thoroughly filled, the cement was allowed to set for twenty-four hours; the pipes were then withdrawn, and screw plugs were placed in the holes. The plan was successful, and the joints have proved water-tight. Twenty-one barrels of Portland cement were used, the hollow sleeves taking seven barrels each; the two sleeves, No. 2 and sleeve No. 1, taking over two barrels each.[1]

The examination of the 6-foot steel pipe (lake extension) was made in May, 1893. It was discovered that the pipe had become disconnected from the old inlet crib, leaving an opening of 2 feet, and had fallen off the cribs or trestles on which it was laid, and in so doing had moved to the eastward. Nearly every joint was disconnected, a heavy drift of sand had formed over the pipe, burying it in many places between 4 feet and 6 feet, and filling the inside to a depth of between 3 feet and 5 feet. The contract to take up and relay this pipe was let to Mr. A. J. Brown, of Toronto, in June, and he commenced work at once. On the 24th July, the first length, nearly full of sand, was lifted and towed to the waterworks dock, and the last length was lifted on the 21st August out of 72 feet of water, of an average temperature of 50°. In the earlier part of the season the water was so cold —being about 43°—that the divers had to wear warm mittens, and throughout all the operations the water never rose to 50° F.

The lifting plant consisted of two large barges or scows, placed 10 feet apart, and fastened at the bow and stern by cross-timbers. Strongly framed derricks were erected at each end; the hoisting tackle being hung over the centre of the well or space between the scows. A steel cable was carried along the derrick to the centre of each scow, dropped to the deck, and carried to the stern in one scow and the bow in the other, and attached to strong crab-winches. It would have been impracticable to dig out a

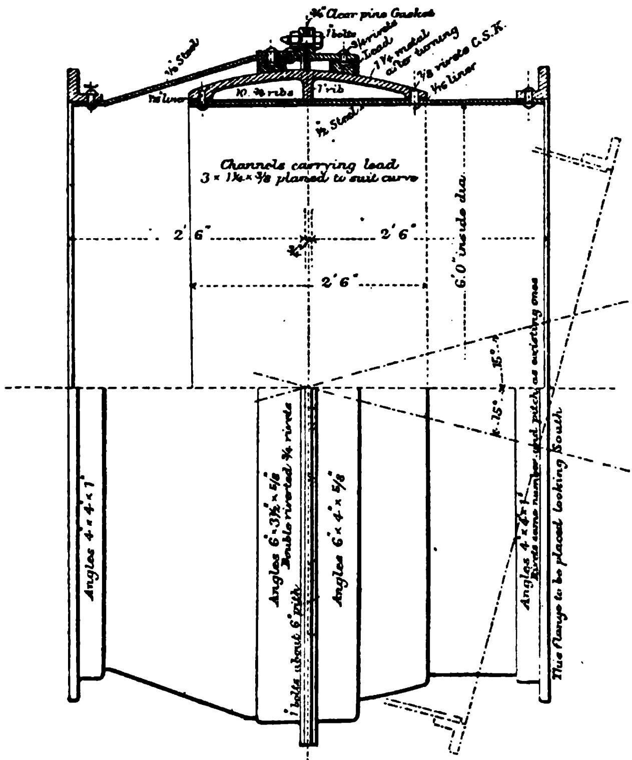
[1] *Engineering Record*, New York, vol. xxxi. p. 41.

50-foot length of pipe which was both embedded in 3 feet or 6 feet and filled to about the same depth with sand; the only course was to lift the pipe by direct force. The method adopted was to anchor the scow immediately over the length to be lifted, and send a diver down to fasten the cable to the bolt-holes in the steel flanges; two 1-inch steel shackles were attached at each end of a length, and they generally withstood the strain. Some of the lengths caused very severe strains on the tackling, shearing the shackles, and two large lifting-hooks 2½ inches by 1¾ inch in cross section, and breaking one ¾-inch steel hawser. No injury was sustained by the flanges on the ends of the lengths which were of rolled steel 4 inches by 4 inches by 1 inch. None of them parted, nor did any of the bolt-holes draw out, and the greatest elongation of any hole was less than ¼ inch. The lifting was successfully performed; none of the pipes were injured by it. All the hoisting was by manual labour. As each length was raised, the two scows with the pipe slung between them were towed to the waterworks dock, a distance of over 4 miles. During this voyage the sand was washed out, and when the wharf was reached the pipes were quite clean. After being hauled out of the water, they were thoroughly examined and tested for water-tightness, and were prepared for the return journey by having water-tight wooden buttons on heads placed on each end, which made them buoyant and easy to tow.

In sinking a length, the scows were brought into position and securely anchored, the pipe being slung between the scows, the heads were taken off, and the pipe lowered; by hauling on the moorings of the scows, the pipe was floated close up to the last-laid length, and the divers had no trouble in making the joints. The relaying was of necessity performed by divers, who bolted up forty-five bolts in each joint, and made a perfectly water-tight pipe. The pipe was tested with an hydraulic pressure of 6 lbs. on the square inch maintained for ten minutes, and gave satisfactory results. The packing-pieces were of pine in two thicknesses of ⅜ inch each, laid cross-jointed. The work commenced on the 15th September, when four lengths and one flexible joint in one section were successfully sunk and laid on the bottom. On the 26th of that month, the first connecting sleeve at the bell-buoy crib was placed in position, and the required length of the last section of the pipe ascertained. The bell-mouth and vertical screen were placed in position on the 5th October, and on the 12th the last length was lowered into position, and over thirty-seven 1-inch bolts put into the end resting in the bell-buoy crib.

On the 13th and 14th a very severe storm raged, and when the divers went down on the 16th, they found the last length torn away from the others, all the bolts being broken and scattered. The flange had been distorted by battering on the other length. The length had slid down about 10 feet southward, and plates on the two first rings were very much indented. It was raised

Fig. 3.



Scale, ¼ inch = 1 foot.

6-FOOT FLEXIBLE JOINT.

and towed ashore for repairs, and eventually laid and bolted in place nine days after the storm. The final sleeve was drawn into place and the caulking completed on the 7th December. The accident to this portion was very remarkable. The injured length was lying in 32 feet of water, where such severe wave-action would not be expected, the bolts were drawn up close, with

very little play, yet they all sheared. The outer end of the pipe was battered about 1½ inch out of the true shape, a special flange had to be made for it, otherwise the pipe was uninjured. The great disturbance of the water at the depth of 32 feet was a surprise to all the staff, and many others who have been engaged in studying the wave-action and currents of the lake in the neighbourhood of the city and island. The movement of the sand is from east to west along the shore, and it was found to be the same at the depths at which the conduit was laid. The fact of the pipe being found on the east side of the trestles and the settlement of the trestles eastwards, is not readily explained. The conduit extension having been completed twelve or fourteen months before the pipes were lifted, the great accumulation of sand was unlooked for, and it is a revelation to many who are studying the physics of the island formation.

An examination was made in November, 1893, of that part of the 6-foot wooden conduit which lies on the shore, and in January, 1894, the work was commenced at the north end of the manhole where it joins the 5-foot steel pipe. A trial was made by sending a diver into the conduit with a 5-inch double-rubber hose, mounted with a 5-inch nozzle which he forced into the sand lying in the conduit; the hose was attached to a centrifugal pump, and the sand was pumped out freely. The diver succeeded in penetrating the conduit for a distance of 80 feet. The experiment being so satisfactory, manholes were cut in the conduit, 160 feet apart, from which the diver worked in both directions. The last manhole was placed at the water's edge, and the pipe was cleared of sand for a distance of 30 feet from it towards the lake. The total length of conduit cleared by this process is 560 feet. Some months after the work had been completed (in the latter part of 1894), a diver ventured, at his own risk, into the 6-feet conduit from the manhole at the water's edge. All the available hose in the city was obtained, and he went in to the full length, 450 feet.

With a view to secure a perfectly safe and clear water-supply, a number of observations of temperature and disturbance were taken at the intake-crib before the pipe was relaid, and it was finally determined to place the mouth of the pipe 17 feet above the bed of the lake. The end of the conduit is turned upwards, and finishes with a large conical screen or grill of wrought-iron bars, placed 1 foot apart along the rim of the pipe. It is stayed to the crib-work with eight 1¼-inch rods with tension buckles. The flexible joints used on this pipe, *Fig. 3*, are remarkable for their immense

size, being the largest in the world, and it is a very gratifying circumstance that they were made in the province.[1]

The cost of the repairs is as follows:—

	£	s.	d.
Conduit repairs	3,276	8	0
Examination of steel conduit	732	6	9¼
„ „ wooden conduit	189	0	0
Lining crib with steel at Hanlan's Point . . .	745	5	4½
Repairing and relaying steel intake pipe . . .	1,512	1	9½
Total . . .	£6,455	1	11¼

The accident which happened on the morning of the 5th September, 1895, in an apparently inexplicable manner, spread alarm and consternation over the city, as it occurred during the heated time of the season, when the water was unusually low, the lagoons being full of decaying dank weeds. The summer holidays were over and the schools had re-opened. It was also the period of the Annual Industrial Exhibition, when large numbers of visitors crowded into the city. The danger of drinking polluted water, likely to cause an outbreak of zymotic disease, was at once recognized, and arrangements were made without delay to supply the citizens with pure drinking-water from water-carts.

The conduit rose in three places, and in settling down fractured three joints. The first was in the 4-foot steel conduit; 230 feet of this pipe, immediately to the north of Hanlan's crib, was floating on the surface of the water, exposing three flexible joints; a length of 115 feet, settled down, leaving the remaining 115 feet above the water. This portion had previously risen in the accident on Christmas Day, 1892. The second was on the 5-foot steel conduit, 1,400 feet to the south of Hanlan's crib. Here the conduit had risen completely out of the water, and broken at the flange joint, leaving the northern portion entirely out of the water and open to the air; the southern portion fell back, the broken flange projecting a short distance above the surface. This portion of the conduit was not disturbed in the accident which happened in 1892. The third was on the 5-foot conduit, 2,100 feet south of Hanlan's crib, where the pipe rose, exposing one of the flexible joints. This portion had been partially disturbed in the accident in 1892, at which time about 300 feet of the conduit had risen.

In his report, Mr. E. H. Keating, the city engineer, recommended the construction of a tunnel from the pump-house to

[1] A large flexible hook-joint, in use on the Syracuse, N.Y., Waterworks Extension, has recently been described, *Engineering News*, vol. xxxii. p. 480.

Hanlan's Point; he also asked for a vote of money to replace the 6-foot wooden conduit with a steel one, the cost of which he estimated at £15,421. A by-law was submitted to the people for this purpose in June, 1895, but it was rejected. Shortly afterwards, in September of the same year, the steel conduit, 5 feet in diameter, rose above the surface of the water for several hundred feet. This led to consultation with Mr. James Mansergh, Vice-President Inst. C.E., who has, in a most comprehensive report, demolished many of the delusions which have enveloped the gravitation schemes, and adopted Lake Ontario as the source of supply. It is pleasing that Mr. Keating's recommendations for the future supply have been thoroughly endorsed by so eminent an authority.

Immediately after the accident occurred, an examination of the conduit was made at each manhole. At the third manhole south of the shore crib, in the 6-foot wooden conduit, a water-logged plank was discovered in a vertical position leaning against the northern face, the top projecting only a few inches above the water, and presenting to the flow of the water its whole breadth of 16 inches. The plank was 8 feet 6 inches in length and 3 inches thick, and the lower end was firmly embedded in the sand, which was 18 inches deep.

The conduit from the shore crib to near Hanlan's Point was laid with the upper surface about 3 feet 6 inches below zero level of the lake, and was left with about 18 inches of cover over it; had it been covered more fully, the weight would have kept the steel pipe in place. The city engineer foresaw the danger and the possibility of another flotation of the conduit, when making repairs after the 1892 accident; he asked for an appropriation for covering the conduit, which was not granted, as such a large expenditure had already been made on repairs. The accident of 1892 had destroyed the hydraulic gradient, the deposit of sand in the conduit, aided by the fall of the water in the lake, impaired the discharging capacity of the conduit, and rendered it insufficient when further reduced by the 16-inch plank found in the third manhole.

The particulars of repair call for no special remark. The 5-foot conduit was disconnected, and two lengths, or 114 feet, taken out. A reservoir was formed by throwing up a large bank of sand at the disconnected pipes, and allowing the lake water to flow into it, the northern portion of the conduit drawing its supply from the reservoir. This plan has worked well throughout the winter. An examination was made of the 5-foot and 6-foot conduits, by divers, who reported considerable deposits of sand, as much as 2½ feet deep in many places. In the 6-foot conduit, the diver

entered from the shore end to a distance of 350 feet, which was as far as the life-lines and hose would reach. He reported deposits of sand.

The costs of the accident were:—

	£
Repairs to conduit	3,348
Forming reservoir on island	1,070
Distributing drinking-water to the citizens .	2,485

A special examination was made of the 6-foot wooden conduit connecting the shore end with the intake-crib in March 1896, which has led to the condemnation of the entire pipe. It was found in a defective condition, and with deposits of sand as deep as 2 feet in many places.

The line of the top of the conduit, *Fig. 2*, is obtained from soundings taken after the accident in 1892. The lake level is given at normal or zero. The water in the lake fluctuates periodically; it reached the lowest known level in 1895, 22 inches below zero, which gives a difference of 6 feet between the highest and lowest recorded levels. It has been falling for the past three years. In September, 1895, it was about 3 feet below the usual summer level; there was not more than 8 inches over the 5-foot conduit in many places, which caused the city engineer much anxiety, as between a conduit with its area reduced by a large deposit of sand in it, and the continuous fall in the lake surface, the prospects of a water famine began to take a possible practical shape. Fortunately this did not occur. The level of the lake is now rising.

In conclusion, it may be mentioned that it is proposed to sink shafts at the pump-house and near Hanlan's crib to a depth of 138 feet below zero level of the lake, which will ensure a safe margin of rock overhead and avoid water-bearing seams. A tunnel will be constructed under the bay for a distance of 5,820 feet, and will be lined with brick; the cross-section will be of horse-shoe shape, 6 feet 6 inches high by 6 feet 6 inches wide. The tunnel, which has been approved by Mr. Mansergh, will have an estimated capacity of 75,000,000 imperial gallons per diem. From the inlet shaft at the south end of the tunnel an entirely new steel conduit will be laid to connect with the north end of the existing 6-foot steel conduit at the bell-buoy crib, to which it will be securely and tightly connected. The southern end of this conduit, between the shore crib and bell-buoy, will replace the 6-foot wooden conduit. It is proposed to lay the new steel conduit on a descending gradient from the lake to the inlet shaft of the tunnel, at a sufficient depth to provide for the delivery of over 40,000,000 gallons per diem at

the pumping station. Provision will be made at the inlet shaft for an additional 6-foot steel conduit, and for emptying and examining the new steel conduit; there will be between 12 feet and 18 feet of covering over it, which will keep it in place and prevent it rising when pumped out for examination. It is also intended to lay a new 5-foot steel connecting pipe from the new 6-foot steel conduit at a point near the inlet shaft to the existing 9-foot steel conduit at a point 1,000 feet to the south of Hanlan's crib, to permit of the supply being maintained whenever it may be deemed advisable to examine the tunnel. The estimated cost of the work is about £110,883.

The Author had no charge of any of the repairs. He is indebted for such detailed information as he was unable to obtain from observation to Mr. Keating, whose courtesy he takes this opportunity of acknowledging.

The Paper is accompanied by two drawings, from which the *Figs.* in the text have been prepared.

(*Paper No. 2908.*)

"English and American Locomotives in Japan."

By Francis Henry Trevithick, M. Inst. C.E.

Japan has a railway system of upwards of 2,107 miles. The country is volcanic and hilly, the centre being occupied by mountains, with peaks attaining heights of between 7,000 and 10,000 feet, and with spurs extending to the coast. The Government adopted the 3-foot 6-inch gauge, and where the lines pass through the mountainous districts in the centre of the main island, they are constructed with a maximum gradient of 1 in 40, and with reverse curves of 15 chains minimum radius. The engines have been obtained chiefly from England; but the Baldwin Locomotive Works of Philadelphia, U.S.A., supplied in 1890 two tender engines, and in 1893 four similar engines for the gradients of 1 in 40, the weight on any one pair of wheels not exceeding 12 tons. Some engines were also ordered from England to work under the same conditions. The principal dimensions of the four classes of engines for hauling the trains between Yama Kita and Numadzu, over the Gotemba Inclines, which are situated on the trunk line between Tokio and Kioto, the new and old capitals of the Empire, are given in Table I. Leaving Yama Kita station (58¾ miles from Tokio) the line passes through seven tunnels, and over several bridges having spans of 200 feet and 100 feet, and in the distance of 27½ miles includes the most important engineering work on this line. The Author has sometimes used this section for carrying out experiments on the hauling-capacity of the engines. On the double line between Numadzu and Gotemba station there are no tunnels and few bridges, the rise being 380½ feet from Numadzu to Sano, and 1,089 feet in the 9 miles 35 chains from Sano to Gotemba. The distance includes a continuous gradient of 1 in 40 for 6 miles with sharp reverse curves, and no compensation for curvature, thus making this section in every way satisfactory to test the hauling and the steaming qualities of the engines.

The double line on this section was completed in March, 1891. Trials previous to this date had to be carried out during the night,

for example, in 1890 engines of Classes A and B each took, on a rainy night, with satisfaction, a train of twenty loaded ballast-wagons, weighing 190 tons, from Numadzu to Gotemba.

On the 3rd, 5th, and 6th May, 1894, more detailed trials were

TABLE I.—PARTICULARS OF FOUR CLASSES OF ENGINES WORKING BETWEEN YAMA KITA AND NUMADZU.

Dimensions.	Class A. American tender engine, 1890.	Class B. English tender engine, 1889.	Class C. English tender engine, 1894.	Class D. English tank engine, 1889.
Cylinders	18 in. by 22 in.	16 by in. 22 in.	17 in. by 22 in.	16 in. by 24 in.
Diameter of bogie-wheels	2 ft. 6 in.	2 ft. 6 in.	2 ft. 6 in.	3 ft. 1 in.
,, driving ,,	4 ft.	4 ft.	4 ft.	4 ft.
,, tender ,,	2 ft. 9½ in.	3 ft.	3 ft.	
Number of drivers	6	6	6	6
Rigid wheel-base	12 ft.	12 ft. 6 in.	12 ft. 6 in.	12 ft. 6 in.
Total length of engine	49 ft.	46 ft. 2 in.	47 ft.	30 ft.
Number of tubes	196 2 in. dia.	178 1¾ in. dia.	178 1¾ in. dia.	170 1¾ in. dia.
Heating-surface of boiler	1,231 sq. ft.	991 sq. ft.	991 sq. ft.	1,009½ sq. ft.
Fire-grate area	18 sq. ft.	16 sq. ft.	17 sq. ft.	15 sq. ft.
Boiler pressure	140 lbs. per sq. in.	160 lbs. per sq. in.	160 lbs. per sq. in.	140 lbs. per sq. in.
Weight on drivers	33 tons 11 cwt.	34 tons 8 cwt.	33 tons 15 cwt.	37 tons 5 cwt.
Total weight of engine	39 tons 7 cwt.	38 tons 12 cwt. 2 qr.	39 tons.	44 tons 15 cwt.
,, tender	21 tons.	16 tons.	22 tons.	
,, engine and tender	60 tons 7 cwt.	54 tons 12 cwt. 2 qr.	61 tons.	44 tons 15 cwt.
Capacity of tanks	2,158 galls.	2,000 galls.	2,400 galls.	1,700 galls
,, coal	60 cwt.	60 cwt.	3 tons.	34 cwt.
Tractive force by formula	14,553 lbs.	13,141 lbs.	14,835 lbs.	12,544 lbs.
One-fifth adhesion weight of engine	15,030 lbs.	15,422 lbs.	15,120 lbs.	16,712 lbs.
Description of boiler	Straight.	Straight.	Straight.	Straight.
Material of barrel	½ inch steel.	½ inch iron.	½ inch iron.	½ inch iron.
,, fire-box	Steel.	Copper.	Copper.	Copper.
,, tube-plate	½ inch steel.	⅞ inch copper.	⅞ inch copper.	⅞ inch copper.
,, tubes	Iron, 13 W.G.	Brass, 12 W.G.	Brass, 12 W.G.	Brass, 12 W.G.
Thickness of inside, back and crown of fire-box	$\frac{5}{16}$ inch; $\frac{5}{16}$ inch; ⅜ inch;	½ inch.	½ inch.	½ inch.

carried out with the American and English engines, Classes A and B. The weather was fine, the road-bed and the rails dry, so that little inconvenience occurred from slipping. Coal was weighed on to the engines, 4½ cwt. being allowed for lighting up, and 1½ cwt.

on each return journey, from Gotemba to Numadzu. The water in the tanks was carefully gauged at Numadzu, Sano, and Gotemba stations. On each trip the engine steamed well. The coal for lighting up is not included in the coal consumption. The test train was made up of twenty-five loaded ballast-wagons, each carefully weighed; Table II gives particulars of the trips and results obtained.

TABLE II.—DETAILS OF SIX TRIPS BETWEEN NUMADZU AND GOTEMBA (15 MILES 29 CHAINS) ON THE 3RD, 5TH, AND 6TH OF MAY, 1894.

Engine.	Load.				Speed.		Work developed at 5 miles per hour.
	Number of wagons.	Weight of wagons.	Weight of engine.	Total weight of train.	Time.	Miles per hour.	
		Tons.	Tons.	Tons.	Minutes.		HP.
A., No. 140	20	183¾	60	243¾	75	12·3	224·25
" "[1]	25	228	60	288			264·96
" "	22	204¼	60	264¼	105	8·8	243·11
" No. 138	22	204¼	60	264¼	100	9·23	243·11
B., No. 55	20	185	54½	239½	78	11·8	220·34
" "[1]	22	204¼	54½	258¾			238·05
" "	21	195	54½	249½	110	8·4	229·54

Engine.	Coal.				Water.		Adhesion Required.
	Lbs. consumed, Up Trip.	Lbs. per Mile, Up Trip.	Lbs. per Mile, Up and Down Trip.	Lbs. per Ton-Mile Up and Down Trip.	Gallons Consumed.	Lbs. of Water per Lb. of Coal.	
							Lbs.
A., No. 140	2,464	160·26	85·6	0·3512	1,443·4	5·87	16,819
" "[1]							19,872
" "	3,416	222·2	116·5	0·4409	1,589·8	4·68	18,233
" No. 138	3,080	200·32	105·62	0·4000	1,510·8	4·9	18,233
B., No. 55	2,576	167·54	89·23	0·3725	1,526·2	5·92	16,525
" "[1]							17,854
" "	3,136	204·0	107·45	0·4306	1,902·0	6·06	17,216

A speed of between 4 miles and 6 miles per hour was maintained over the heaviest parts of the line. If the speed was lower than 4 miles per hour the danger of stopping was very great. The relative tractive-force of the American engine, 14,553 lbs., and of the English engine, 13,141 lbs., was very nearly as 11 to 10. The load hauled by the engines is nearly in the same ratio, namely, 204¼ tons to 195 tons. Allowing 69 lbs., the resistance

[1] Stopped at the first curve after leaving Sano station

per ton in lbs. at the rails, the tractive-force required from the American engine to move 204¼ tons + 60 tons for the engine = 264¼ tons = 18,233 lbs. The weight on the driving-wheels was 75,152 lbs., and the coefficient of friction, or ratio of tractive-force to weight on the driving-wheels, $\frac{1}{4 \cdot 12}$. With the English engine to move 195 tons + 54½ tons for the engine = 249½ tons required a tractive-force of 17,216 lbs. The weight on the driving-wheels was 77,056 lbs., and the ratio of tractive-force to weight on the driving-wheels $\frac{1}{4 \cdot 47}$.

The coal consumption increases rapidly when extra load is added to an engine already heavily loaded. In the case of the American engine, No. 140, with a train of twenty wagons, weighing 183¾ tons, the coal-consumption is 160·26 lbs. per mile up the incline; with twenty-two wagons, weighing 204¼ tons, an increase of 11 per cent., the coal-consumption is 222·2 lbs. per mile, an increase of 33 per cent. In the case of the English engine, No. 55, with a train of 185 tons, the coal-consumption is 167·54 lbs. per mile up the incline; with a train of 195 tons, the consumption is 204 lbs. per mile; the increase of the load is 5·4 per cent., and of the coal 21 per cent. Engine No. 138 burned 11 per cent. less coal than engine No. 140, when working a similar train. Engine No. 138 had a 4¼-inch exhaust-nozzle and no deflector-plate in the smoke-box; engine No. 140 had a 4-inch exhaust-nozzle and a deflector-plate in the smoke-box. The amount of coal consumed per minute of each trip is very similar, nearly 33 lbs.

The failures of the American engine, No. 140, with twenty-five loaded wagons, weighing 228 tons, and of the English engine, No. 55, with twenty-two loaded wagons, weighing 204¼ tons, both occurred at the first curve on the 1 in 40 gradient, after leaving Sano station. The trains were assisted beyond this curve, but came to a stand again at the second curve; in each case the full pressure of steam was used,[1] the regulator was opened wide, and the lever in full gear.

The English tender-engines, Class C, with 17-inch cylinders and 22-inch stroke, were not erected at the time of this trial; and the English tank-engines, Class D, with 16-inch cylinders and 24-inch stroke, were working on other sections of the railways,

[1] At the first failure of Engine No. 140 the boiler pressure was 154 lbs. per square inch, and at the second failure was 148 lbs. per square inch.

and consequently could not be included in these trials of hauling capacity.

The actual consumption of coal and oil of the different classes of engines, and the average number of vehicles per train, as worked between Yama Kita and Numadzu, over the Gotemba incline, from April, 1890, to the end of September, 1894, are shown in Table III.

TABLE III.—CONSUMPTION SHEET.

No. of Engine.	Mileage.	Coal.		Oil.		Average Vehicles per Trip.	Remarks.
		Cwt.	Lbs. per Mile.	Pints.	Pints per 100 Miles.		
		American Engines, Class A.					Started.
No. 101	93,496¼	61,095½	73·19	12,076	12·81	14·45	Oct., 1890
„ 103	82,908	54,386½	73·49	10,065	12·14	14·64	Jan., 1891
„ 138	15,259¾	10,826	79·46	2,437	15·97	14·80	Feb., 1894
„ 139	16,150	11,521	79·90	2,633	16·30	14·77	„ „
„ 140	16,188	10,131½	70·10	2,987	18·45	14·99	„ „
„ 141	16,108½	9,910	68·90	2,896	17·98	14·40	„ „
	240,110½	157,870½	73·64	33,094	13·78	14·68	
		English Engines, Class B.					
No. 54	113,438½	58,628	57·88	12,399	10·93	16·49	April, 1890
„ 55	119,165½	60,671½	60·87	13,942	11·70	15·51	„ „
„ 56	36,088¾	17,100	53·14	5,191	14·40	11·53	May, „
„ 57	85,227½	43,329	56·91	9,568	11·22	16·24	Mar., 1891
„ 58	43,435	21,296	54·91	4,273½	9·84	15·85	July, „
„ 59	70,500¾	38,565	61·27	8,008½	11·36	15·31	April, „
	467,856	239,589½	57·35	53,382	11·41	15·16	
		English Engines, Class C.					
No. 149	3,376½	2,006	66·55	678	20·08	14·19	June, 1894
„ 150	2,798	1,660	66·45	812	29·02	14·90	„ „
„ 152	7,507	4,072	60·75	1,454½	19·38	13·36	„ „
	13,681½	7,738	63·34	2,944½	21·51	14·14	
		English Tank-Engines, Class D.					
No. 109	75,185¼	34,744½	51·76	7,669	10·20	14·83	May, 1891
	796,833¼	439,942½	61·88	97,089½	12·20	14·70	

Of the engines of which the performances are given in the Table, a just comparison of results, since the conditions of the traffic, the working of the line and the time of year is similar, is afforded between two engines of Class A, Nos. 101 and 103, and

one engine of Class D, No. 109. These engines have always been stationed at the Yama Kita engine-shed until transferred to other sections during February and March 1894. Engines Nos. 101 and 103, Class A, worked for eighty months, running a mileage of 176,404, an average of 2,205 miles a month per engine, with 73·33 lbs. of coal per mile, 12·47 pints of oil per 100 miles, and a train of 14·50 vehicles per mile. Engine No. 109, Class D, ran thirty-three months with a mileage of 75,185, or an average of 2,278 miles per month, with 51·76 lbs. of coal per mile, 10·20 pints of oil per 100 miles, and a train of 14·81 vehicles per mile. Of the six engines of Class B, during the period from April 1890 to September 1894, four were stationed at Numadzu engine-shed, and if an engine at either station required repair, an engine of Class B replaced it, otherwise they were used on another section. The four other engines of Class A started working in February 1894, and the three engines of Class C in June 1894, so that comparison of these with the other engines would hardly be a just one, as the service is too short.

The train-service over the Gotemba incline during this period was worked by seven engines, three stationed at Yama Kita, and four at Numadzu. The following Table is taken from the official locomotive returns.

TABLE IV.—MILEAGE OF DIFFERENT CLASSES OF ENGINES ON THE GOTEMBA INCLINE TO THE 30TH SEPTEMBER, 1895. CONSUMPTION SHEET.

Class of Engine.	Number of Engine.	Mileage.	Coal.		Oil.	
			Cwt.	Lbs. per Mile.	Pints.	Pints per 100 Miles.
Class A . . .	6	343,118	221,244	72·22	51,974	15·15
„ B . . .	6	467,856	239,382	57·35	53,382	11·41
„ C . . .	10	210,341	120,512	64·17	34,605	16·45
„ D . . .	1	75,185½	7,669	51·76	7,669	10·20
. .	..	1,096,500	588,807	60·00	147,630	13·44

The maximum load in ordinary weather is the same for the four classes of engines:—

	Tons.
7 bogie carriages	130
or 16 carriages on two pairs of wheels.	130
or 18 wagons „ „ „	140

A bogie carriage weighs when empty 15 tons; the first and second class composite carriages seat forty-four passengers; the

third class seat eighty-two; the length over the body being 46 feet 6 inches. The average weight of a carriage on two pairs of wheels is 6½ tons when empty; the first class seat twenty passengers; the second class twenty-six; the third class forty-six; the length over the body being 23 feet 8 inches. All the passenger carriages and luggage-vans are fitted with the vacuum automatic brake. The wagons are open and covered, and of two distinct classes. Those having the underframes all iron and arranged to carry 10 tons, the average weight when empty is 5¼ tons; the other wagons having iron sole-bars and wood underframes to carry 7 tons, the average weight when empty being 4¼ tons. In calculating the number of vehicles per train, a bogie carriage is counted as two and a half ordinary carriages. The 10-ton wagons are counted as one and a half 7-ton wagons.

The time-table speed of passenger trains up the gradient is 14 miles, and down the gradient 22½ miles per hour. The coal used is well adapted for locomotive purposes, being free from injurious gases, with little ash, and keeps steam well, although rather soft and smoky. The collieries are in the island of Kiushiu, and the island of Yezo; in either case it is transported by sea 600 miles to Tokio. The average price of coal per ton during 1894 may be taken at about 13*s*. Rape-seed oil is used and costs 15*d*. per gallon. It is not so suitable as a mineral oil, as in the summer it is too thin, and in the winter too thick. The average engine-mileage per annum run over the Gotemba incline is 200,000 miles. Table V shows the expense and the saving for one year of the coal and oil by using the different classes of engines. The saving in coal and oil of £1,297 17*s*. on the tank-engine over that of the American tender-engine on each 200,000 miles run, is an important item and worthy of consideration. The engines of class A and of class D were stationed at the same engine-shed and worked similar trips. The Locomotive Department expenses for the same year is about 5*d*. per engine-mile.

TABLE V.—CONSUMPTION OF COAL AND OIL FOR 200,000 MILES.

Class of Engine.	Mileage for One Year.	Coal.			Oil.			Total Expense.		Saving for One Year.	
		Tons.	Price.		Gallons.	Price.					
			£.	s.		£.	s.	£.	s.	£.	s.
Class A	200,000	6,575	4,274	7	3,445	215	3	4,489	10	..	
„ B	200,000	5,120½	3,328	3	2,852	178	3	3,506	6	983	4
„ D	200,000	4,666	3,032	9	2,550	159	4	3,191	13	1,297	17

CONSUMPTION SHEET AND MILEAGE ON THE GOVERNMENT RAILWAYS FOR THE YEAR ENDING THE 31ST MARCH, 1894.

Length of Line.	Engine Mileage.	Coal.		Oil.	
		Tons.	Lbs. per Mile.	Gallons.	Pints. 100 Miles.
557½	4,126,127½	57,591½	31·26	53,200	10·31

The private railways with 1,550 miles had an engine-mileage of 5,257,999 for the same year. The length of open railway is 2,107 miles, and about 500 miles require heavy engines on account of the gradients, so that the coal-consumption is an important item with these engines.

Several American engines have been purchased by the private railway companies for working on the level and the gradients; and although the Japanese engineers are reticent on the subject of fuel-consumption, in all cases remarks have been made on the excessive coal-consumption as compared with the English engines.

The Paper is accompanied by diagrams of the Gotemba inclines, and of the four types of locomotives referred to.

[APPENDIXES.

APPENDIXES.

APPENDIX I.

TABLE SHOWING THE COMPARATIVE WORKING OF COMPOUND AND NON-COMPOUND LOCOMOTIVES ON THE IMPERIAL GOVERNMENT RAILWAY AND ON THE CHIKUHO RAILWAY COMPANY.

——	Imperial Railway.		Chikuho Railway.		
Number of engine	221	179	9	8	7
Type " "	Compound.	Non-compound.	Compound.	Non-compound.	Non-compound.
Where built	Japan.	England.	America.	America.	America.
Engine-miles, total	6,403·5	6,390·5	3,259·3	2,874·0	3,228·6
Number of vehicles per train, average	12·89	13·24	26·81	23·80	25·67
Weight of train, including load, average . tons	94·36	94·71	180·70	165·20	172·40
Ton-miles, total	604,203	605,272	588,956	474,785	556,611
Coal-consumption, total . lbs.	121,170	138,445	135,200	124,020	145,530
Coal-consumption per engine-mile . . lbs.	18·92	21·66	41·48	43·15	45·08
Coal-consumption per ton-mile . . . . lbs.	0·2005	0·2287	0·2296	0·2612	0·2615
Ton-miles per ton of total coal	11,172	9,794	9,756	8,576	8,566
Increase of ton-miles over Chikuho No. 7 . . . per cent.	30·42	14·34	13·89	0·12	..

Engine No. 221 is the first locomotive built in Japan, and commenced running on the 26th May, 1893, the total mileage up to 15th December, 1895, being 74,991. It is an outside-cylinder compound tank locomotive, the high-pressure cylinder being 15 inches in diameter, with a stroke of 20 inches. The low-pressure cylinder is 22½ inches in diameter and has the same stroke. Both valves are fitted with Joy radial valve-motion. The heating-surface is 769·57 square feet; the grate-area, 12·4 square feet; and the working pressure, 150 lbs. per square inch. It has eight wheels, four-coupled, 53 in inches diameter; leading- and trailing-wheels, 38 in inches in diameter, fitted with Webb radial axle-boxes, an extreme wheel-base of 19½ feet, and a rigid wheel-base of 7½ feet. The weight of engine in working order is 40 tons; that available for traction being 25½ tons. The capacity of the water-tanks is 1,000 gallons; coal, 25 cwt.

Engine No. 179 is non-compound, but otherwise similar to No. 221, with cylinders 14 inches diameter and 20 inches stroke.

Engine No. 9 is a four-cylinder compound, having two high-pressure cylinders, 11 inches diameter, and two low-pressure, 19 inches diameter, all 22 inches stroke; with six wheels, coupled, 4 feet diameter; the heating-surface being 1,379 square feet; and grate-area, 21 square feet.

Engines Nos. 8 and 7 (non-compound) have cylinders 17 inches in diameter and 22 inches stroke, and agree with No. 9 in the other particulars given. All three American engines, Nos. 9, 8 and 7, are from the Baldwin Locomotive Works, and all carry 29½ tons on driving-wheels; their working pressure is stated as 140 lbs. per square inch.

A duplicate engine of No. 9 (four-cylinder compound) was borrowed from the Sanyo Railway Company and tried on the gradient of 1 in 40 on a section of the Government Railway between Kioto and Baba. In full gear and with a pressure of 175 lbs. per square inch, it took with difficulty over this section a train of 158 tons, exclusive of the engine, at a speed of about 5 miles per hour. These particulars were supplied by the Railway Department, as the Author was not present at these trials.

APPENDIX II.

Trials of Locomotives on the 1 in 40 and 1 in 15 Gradients.

In Table I are given particulars of the two classes of locomotives working on the Abt system over a section of the Government Railway.[1] Table II shows the consumption of fuel and water, and the hauling capacity of the more recently introduced type when first put to work:—

Table II.—Trials of Locomotives Nos. 168 and 169

No. of Trials.	No. of Engine.	Up Gradient. Load pushed by the Engine. No. of Wagons.	Load pushed by the Engine. Weight.	Average Speed per Hour.	Total Distance the Engine run	Coal Consumption. Total.	Coal Consumption. Average per Mile.	Water Consumption. Total.	Water Consumption. Average per Mile.	Total Time of Running, including any Stoppages.	Water Evaporated per lb. of Coal.	Rate of Evaporation per Hour.
			Tons.	Miles	Miles	Lbs.	Lbs.	Gallons.	Gallons.	Mins.	Lbs.	Lbs.
1	168	10	94	4·6	2·9	1,120	382·6	673·4	230·0	42	6·0	9,620·1
2	168	12	113	4·2	2·9	1,232	420·9	770·8	263·3	46	6·3	10,053·4
3	169	10	92	4·3	2·8	896	322·8	587·2	211·5	41	6·6	8,593·2
4	169	11	100	4·6	2·9	907	309·9	698·7	238·7	43	7·7	9,749·4
5	169	12	113	4·1	2·9	1,176	401·8	730·7	249·7	46	6·2	9,531·4
6	169	12	113	4·5	2·9	1,232	420·9	730·7	249·5	41	5·9	10,688·0
7	169	8	76	6·8	2·9	840	287·0	539·7	184·4	27	6·4	11,994·0

Note.—The consumption should be reduced 5 per

[1] See also Minutes of Proceedings Inst. C.E., vol. cxx. p. 43.

TABLE I.—PARTICULARS OF ENGINES.

——	Four Engines.	Two Engines.
Where built	Germany	England
Date of trials	Feb. 1893	Oct. 1895
Adhesion Engine.		
Diameter of outside cylinders . . . . . inches	15·35	$15\frac{1}{2}$
Stroke . . . . „	19·68	20
Coupled wheels	6 wheels 35·43 inches diameter	6 wheels 3 feet diameter
Number of wheels	6	8
Rigid wheel base . . . . feet	11·8	13
Weight on coupled wheels . . . . . . tons	33·45	39
Weight on engine . . . . „	33·45	$51\frac{1}{2}$
Rack Engine.		
Diameter of inside cylinders . . . . . . inches	13·38	$11\frac{3}{4}$
Stroke . . . . „	15·75	16
Diameter of rack-wheel . . . . „	22·55	$22\frac{9}{16}$
Heating-surface . . . . sq. feet	807·11	1,270
Area of fire-grate . . . . „	18·5	20·1
Ratio of grate-surface to heating-surface . . .	1 to 43·5	1 to 63
Boiler-pressure . . . . lbs.	176·7	180
Capacity of tanks . . . . gallons	800	1,150
„ „ fuel . . . . cwt.	20	30

ON THE 1 IN 40 AND 1 IN 15 GRADIENTS, OCTOBER, 1895.

Up Gradient.												Down Gradient.	
On 1 in 40 Gradient.						On 1 in 15 Gradient.							
Distance.	Coal Consumed.	Coal Consumed per Mile.	Water Consumed.	Water Consumed per Mile.	Consumption of Coal per Ton-Mile.	Distance.	Coal Consumed.	Coal Consumed per Mile.	Water Consumed.	Water Consumed per Mile.	Consumption of Coal per Ton-Mile.	Average Speed per Hour.	Water Consumed for Cooling Cylinders and Feeding Boiler.
Miles	Lbs.	Lbs.	Galls.	Galls.	Lbs.	Miles	Lbs.	Lbs.	Galls.	Galls.	Lbs.	Miles	Galls.
1·2	222·6	175·8	133·9	105·7	1·87	1·7	897·4	540·3	539 5	324·8	5·75	6·8	92·9
1·2	211·2	166·8	132·1	104·4	1·48	1·7	1,020·8	614·6	638·6	384·5	5·45	6·5	103·9
1·2	190·3	150·3	124·7	98·5	1·69	1·5	705·7	467·3	462·5	306·3	5·24	5·9	236·0
1·2	149·4	118·0	115·1	90·9	1·21	1·7	757·6	456·1	583·6	351·3	4·66	6·1	81·4
1·2	185·3	146·3	115·1	90·9	1·30	1·7	990·7	596·5	615·6	370·6	5·29	5·5	114·4
1·2	299·0	180·9	135·8	107·2	1·61	1·7	1,003·0	603·9	594·6	358·0	5·36	7·0	81·9
1·2	137·4	108·5	88·3	69·7	1·44	1·7	702·6	423·0	451·5	271·8	5·60	7·3	92·9

cent. after the engines have run a few months.

In consequence of the small heating-surface provided to the four locomotives tried in February, 1893, they proved unable to take up the incline more than two-thirds of what was expected, and 60 tons to 70 tons of train-load at 4·7 miles an hour has been the limit of their capacity in ordinary work. The consumption of the four German engines during two years ending 31st March, 1895; 95,000 miles, 108,518 cwt. of coal, 129 lbs. per mile; 51,524 pints of oil, 54·23 pints per 100 miles. In ordering two locomotives from Messrs. Beyer, Peacock and Co., instructions were given for more heating-surface, a larger grate-area, and stronger frames and working parts, thereby bringing the weight of the locomotive to 51½ tons on four pairs of wheels.

Table II gives particulars of the trials of the two engines on the Usui section, which took place from the 20th to the 25th October, 1895, and which proved the locomotives to be satisfactory in steaming, combustion of fuel, and pushing qualities. The cut-off of the inside cylinders (rack engine) and of the outside cylinder (adhesion engine) was between the second and third notch, the quadrant being divided into five notches. The regulator opening of the inside and outside cylinders was ⅜ to ½ of the full opening. The temperature of water in the tanks was about 75° F. The coal consumed on the up and down trips is half that on the up trip per mile. In most trips one stop was made on the 1 in 15 gradient to test the starting qualities. The engines steamed freely, the needle of the pressure-gauge being steady during the run. The boiler would allow of another inch in diameter to the inside cylinders. The distance of 1·2 mile on the 1 in 40 gradiont and of 1·7 mile on the 1 in 15 gradient is sufficient to test the hauling and steaming qualities of the engines.

(*Paper No. 2917.*)

"Dredging the Approaches to Ports on Lake Titicaca, Peru."

By Edward George Clark, Assoc. M. Inst. C.E.

Lake Titicaca[1] is situated at an elevation of 12,500 feet above the level of the sea on the table-land between the Peruvian and Bolivian cordilleras. Its longtitude is between 68° and 70° W. and its latitude between 15° and 17° S. It has an average breadth of 30 miles, and is 120 miles long, the area being about 3,500 square miles. The water is so slightly brackish that it is palatable, and is never frozen over, ice only forming on the edges, in sheltered places. Its chief feeders are the rivers Huancane, Suchis, Hachacache, Vilque, Pomata, Juli, Ilave, Coata, and the Ramis, the last rising in a small lake, La Raya, from which also flows an affluent of the Ucayali, one of the main tributaries of the Amazon. The only outlet is the River Desaguadero, which, after a course of nearly 300 miles, loses itself in the shallow lake Poöpo. When the lake is low, after seasons of scanty rain, the water from the River Desaguadero has been known to flow into Lake Titicaca.

It is stated that the level of the lake is gradually falling, so that while three hundred years ago its waters washed the ancient ruins of Tiahuánaco in Bolivia, these are now 12 miles from its shores, and 130 feet above it. On the Isthmus of Yunguyo, which connects the Peninsula of Copacabana with the mainland, at about the same level, there are traces of an old canal, which enabled the Balsas, or native reed boats, to pass from one side to the other. The fall does not, however, appear to be continuing, as, during the rainy season of 1895, the water has reached a higher level than in 1875, when it was higher than it had been for many years. The rise of the lake in the year 1893 was 43½ inches and the fall 32 inches; in 1894 the rise was 51 inches and the fall 23½ inches; and in 1895 the rise was 32½ inches and the fall 26 inches. The rainy season commences in December and ends in

[1] The name signifies in the Aymará language "cat-rock."

April. Lake Titicaca appears to be a volcanic basin, as pieces of lava, porphyry and jasper are often found on its shores, and igneous rocks occur among the sedimentary strata. The lake is much deeper in the north than in the south, soundings of 700 feet being frequent in the northern part, of 1,600 feet near the Island of Titicaca, and of only 20 feet or less in the southern portion.

The chief town on the lake, Puno, has about 6,000 inhabitants, and is the terminus of the Southern Railway of Peru, which starts from the Port of Mollendo on the Pacific coast. The line passes over the Andes at an elevation of 14,666 feet above the sea, and its length is 325 miles. The silver mines of Puno were in the seventeenth century regarded as inferior only to those of Potosi, but they are not much worked now. From Puno, three screw-steamers of light draught, the largest being the "Coya" of about 570 tons, belonging to the Peruvian Corporation, navigate the lake, which is on the highway from the coast to La Paz, the commercial capital of Bolivia.

The River Desaguadero was surveyed, in the year 1891, by Mr. J. C. Coode, M. Inst. C.E., and on his recommendation a dredger was sent out to improve the channels of the river and also the approaches to the ports of Puno, Chilelaya and Desaguadero on Lake Titicaca. The traffic on the River Desaguadero is important, as a considerable portion of the ore from the exceedingly rich copper mines of Coro-coro is brought up to its mouth, and trans-shipped to the lake steamers. As the steamers on the river, which are of the stern-wheel type, are of shallow draught, the dredger was designed to cut to a depth of only 8 feet below the level of the water. It was supplied to the Peruvian Corporation by Messrs. Hunter and English, and is 80 feet long by 20 feet beam by 7 feet deep at the centre, the draught being 3 feet. It is arranged to deliver the spoil either on to the banks of the river, or into barges alongside. It is also fitted with a propeller to enable it to move short distances without the aid of a tug. The vessel is divided into three water-tight compartments, and a pontoon can be attached to each side by bolts to carry the sheer-legs, which support the shoots for delivering the spoil on to the banks, each shoot projecting 100 feet from the centre of the vessel. The engines are of the compound surface-condensing inverted type, having cylinders 9 inches and 18 inches in diameter, by 18 inches stroke, with air-feed- and bilge-pumps, driven off the low-pressure crosshead. An independent centrifugal pump supplies the circulating water, and also the shoots. There is a steel return-tube boiler, 6 feet 6 inches in diameter by 8 feet long, which furnishes

steam at a pressure of 90 lbs. per square inch. The furnace is so arranged that it can burn either coal, llama dung, or petroleum, the Holden jet being used in the last case. The donkey-pump is fitted to pump from the lake, the bilge, or the fresh-water tank, and delivers to the boiler, deck, or over the side of the vessel.

The bucket-ladder is 49 feet 6 inches long and 3 feet deep at the centre, and is constructed of two steel-plate girders strongly braced together, carrying bucket-rollers on the top side. It is supported at the upper end by an independent cast-steel shaft, and at the lower end by the bale frame and wire-rope tackle; the hoisting gear being worked off the main shafting by friction gear. There are twenty-eight buckets, each of 3·2 cubic feet capacity, having cast-steel backs, mild-steel bodies and lips, and fitted, in addition, with an automatic ejecting back, which enables the stiffest clay to be discharged without waste. The links are of wrought-iron bushed with steel. The six deck-winches are of the Hunter type, having two speeds, worked from the main engine; and they are so arranged that one man can work the set.

The dredger was erected in London, and, after a trial of the machinery, all parts were marked, taken to pieces, packed and shipped for Mollendo. It was there landed and packed on to ten cars for haulage across the Andes, being delivered into a siding on the edge of Lake Titicaca, about 2 miles from Puno. The first plate was laid on the 7th of March, and the hull was launched on the 6th of May, 1893. The dredger left, under her own steam, on the 21st of August for a point in the bay, about 2 miles distant, ready to start work. The total cost of the dredger, erected at Lake Titicaca, was £8,164 10*s.*

For improving the steamer service on the lake it became necessary to widen and partly straighten the existing channels by cutting off corners, or to cut an entirely new channel across the shallows forming the entrance to Puno Bay. It was found that the cost would be about the same in both cases, while the advantages of the latter would be, first, that the passage to Bolivian ports would be shortened about 2 miles; secondly, the channel would be perfectly straight; and, lastly, the traffic of the steamers would not be interfered with during the dredging operations. Work was commenced on the 23rd of August, 1893, and the channel was completed on the 30th of June, 1894. A crew of eight men was carried, and was sufficient for all purposes. The total number of working days was 268, the number of hours spent in effectual work being 1953·5. The amount of spoil delivered on the banks was 137,615 cubic yards, or 70·4 cubic yards per

hour, or 611·6 cubic yards per working day for 225 days, the actual time occupied in effectual running. As the contract was to deliver 50 cubic yards per hour, or 500 cubic yards per day of ten working hours, the dredger greatly exceeded the guarantee.

The best month's work was 20,945 cubic yards when in light material, and this was delivered in 224 hours, or at an average rate of 93·5 cubic yards per hour. The material dredged was entirely alluvial deposit mixed with minute shells, fully two-thirds being very hard and compact. The total length of the channel was 12,044 feet; one cut only was necessary for 2,973 feet, but two cuts were required for 4,675 feet, and three cuts for 4,396 feet. The top cut was 60 feet, the intermediate was 55 feet, and the bottom 40 feet wide. For a distance of 3,000 feet the dredger had to cut its own flotation, as, owing to the shallowness of the water, it was not able to float over the banks, and for 800 feet of that distance the land was about 6 inches above the level of the water. After the first and second cuts were finished, it was necessary to lengthen the ladder 6 feet to enable the buckets to cut to a depth of 15 feet 3 inches, to allow for a fall of the lake of 5 feet 3 inches, the water having risen very rapidly after a series of dry seasons. The additional length of 6 feet allowed a deeper cut of 4 feet 6 inches. Previously, the vessel had been working at 10 feet 9 inches from the water-level, although the contract was for 8 feet only. The channel has been buoyed, the buoys being 80 feet apart, at intervals of 860 feet. Reeds have also been planted, and in course of time they will take the place of the buoys.

The cost of the 137,615 cubic yards dredged was 1·95*d.* per cubic yard, including all charges for work done except interest on capital and depreciation. The cost of coal in lighters alongside was £3 4*s.* 9½*d.* per ton. It came from New South Wales, and its cost amounted to 2·49 lbs. per cubic yard dredged.

The works described have been carried out by local labour, under the superintendence of the Author, who went out with the dredger. His thanks are due to Mr. V. H. MacCord, the Superintendent of the Southern Railway of Peru, for furnishing the particulars of costs.

The Paper is accompanied by a chart of Lake Titicaca, and by a longitudinal- and three cross-sections of the new channel.

(*Paper No. 2953.*)

"Machinery Bearings."

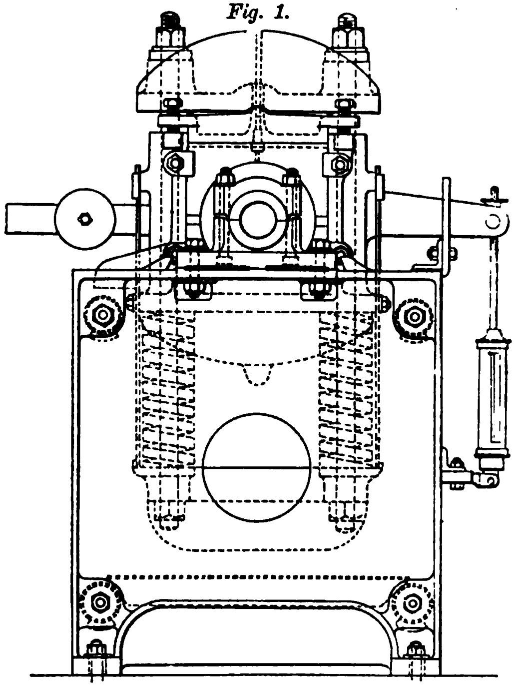
By JOHN DEWRANCE, Assoc. M. Inst. C.E.

IN this Paper are presented the results of a series of experiments undertaken by the Author to determine the frictional resistance to shafts revolving in bearings under varying loads, when subjected to different conditions. The testing-machine used is shown in *Figs. 1.* The journals upon which the experiments were made were 10 inches and 4 inches respectively in diameter, and formed part of a shaft supported at its ends in plummer-blocks. A saddle rests upon the upper bearing and is connected through four bolts compressing springs to a plate pressing upon the under side of the lower bearing. The load carried by the journal can therefore be varied with the degree of compression of the springs, the pressure upon the upper bearing being greater than that on the lower by an amount equal to the total weight of the saddle, spring and bearings, generally about 16 cwt. It was not convenient to apply a thermometer to the lower bearing, so the observations were usually confined to the upper one, which, having to support the greatest load and being at a disadvantage as regards lubrication, generally failed first. When the saddle had been fitted with a pair of bearings the four bolts were evenly screwed up, the amount of compression being indicated by scales and pointers on each side. When loaded, the saddle was free to turn with the shaft through a certain range, and a spring balance, fitted, as shown in the *Fig.*, to retain the saddle vertical, indicated the amount of the force required to turn the shaft.

The first experiments were made upon a pair of 10-inch by 16-inch bearings having two oil-holes on the top centre-line. They were carefully fitted about $\frac{1}{64}$ inch larger in diameter than the journal, but they would not run cool with the weight of the saddle alone. When a channel was made to connect the two holes and to lubricate the part of the bearing between them, the result was not greatly improved. When oil was thrown upon the shaft at the openings between the bearings they began at once

to sustain loads more or less satisfactorily, but the oil issued from the holes at the top. The pressure indicated on a gauge connected to the centre of the bearing was equal to the greatest load that could be applied to the large bearing; the experiments were, therefore, transferred to the 4-inch shaft with a bearing upon which the same load represented a greater pressure. A long series of experiments resulted ultimately in a pressure of 2,300 lbs. per square inch being recorded. The bearing was taken

Fig. 1.



END VIEW.

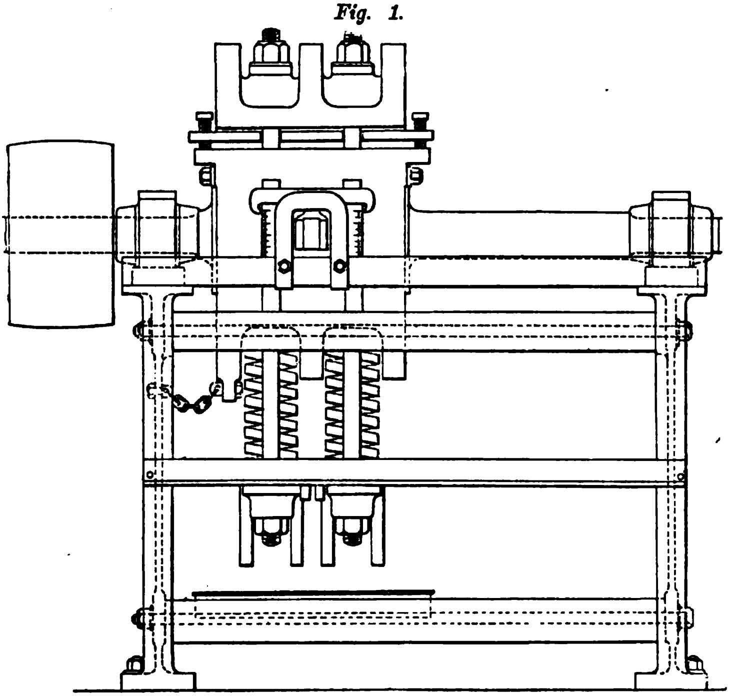
Scale, ¼ inch = 1 foot.

FRICTION-TESTING MACHINE.

out and the surface dressed with a view to obtaining even greater pressures. When, however, it was replaced the following day, instead of continuing to deliver oil at the gauge connection as hitherto, the bearing would take oil rapidly. The pressure-gauge was removed and a vacuum-gauge substituted when it was found that a vacuum equivalent to 30 inches of mercury existed where previously a high pressure had been recorded. The bearing still ran cool and well, as shown in Table I of the Appendix.

When taken out there was nothing in its appearance that at first sight accounted for the change described, but further examination revealed that, although the back of the bearing had been planed, it was, from some cause, not quite flat, the centre of the bearing taking all the load. This had sprung the bearing slightly and had worn the central part of the surface. When the load was removed the centre sprang back, leaving that part of the surface round the hole separated from the shaft. The load

Fig. 1.



ELEVATION.

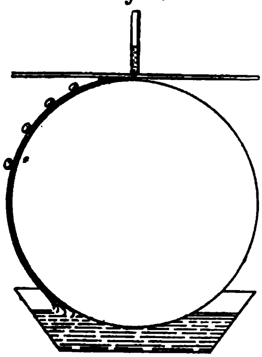
Scale, ¼ inch = 1 foot.

FRICTION-TESTING MACHINE.

applied during subsequent experiments had not been sufficient to spring the bearing flat again. The experiments on this point were continued until a bearing was produced that, when placed on to the shaft one way, gave a pressure in a hole at the centre of the bearing and, when reversed, gave a vacuum at the same point. As a result of the observations made during the foregoing experiments an arrangement was set up which is shown diagramatically by *Fig.* 2 to illustrate the way in which oil lubricates a bearing.

If oil is slowly poured on to a revolving shaft, it accumulates in a thick ring, most of which can be wiped off by the hand. The oil next to the shaft adheres more firmly than that which is further away. If the oil ring be imagined to be composed of films of oil, each of the thickness of a molecule of oil, the first film has the solid shaft to adhere to. The second is separated from the shaft, but it can adhere to the first, which is itself firmly held. Each successive film is less influenced by the force of adhesion that exists between the shaft and the oil, until the point is reached at which centrifugal force is stronger than the adhesion and the oil flies off the shaft. If a shaft be rotated in a bath of oil, the ring of oil is also formed. In *Fig. 2* the circle represents a shaft, on the top of which a flat plate rests. However light this plate may be, it affects the ring of oil immediately it touches it. Unless the plate entirely stops all the oil from passing round with the shaft it must float upon that part of it which remains between it and the shaft. There must, in other words, be a film of oil at a sufficient pressure per square inch acting on the narrow surface of contact to support the total load put upon the plate. This pressure is the result of the multiplication of the force of adhesion of the oil to the shaft by the inclined plane formed by the plate to the shafts.[1] The velocity of the oil is also increased in the same way. If the load on the plate is a light one the adhesive force is sufficient, when increased by the inclined plane, to produce the pressure required to lift the plate and carry several films round with the shaft; but, as the load is increased, fewer films are able to pass the plate until the point is reached at which the surfaces abrade one another for want of lubrication.

Fig. 2.



If a hole is made through the plàte, this pressure can be observed, increasing as the hole approaches the point at which the plate rests upon the shaft. If the hole is pushed beyond this point a vacuum is produced. The oil and air in the hole adhere to the films and are carried round with the shaft by surface adhesion. A flat plate was employed in this experiment, as it was easier

---

[1] Another explanation of the phenomenon is given: see "On the Conversion of Heat into Work," by Dr. William Anderson, F.R.S., 2nd edition, p. 19.—Sec. Inst. C.E.

to observe the relative position of the hole. The conditions are not greatly changed if the diameter of the shaft be reduced and the plate curved. A bearing that exactly fits the shaft all the way round will not run cool, and the well-known fact that a bearing must not be tight at the side indicates that the inclined plane must exist in some form or other. All successful bearings are constructed with an inclined plane in some form, and the load that a bearing will sustain is determined by the inclination. If the angle is sharp it will not multiply the adhesion of the oil so much as if it is more gentle. By suitably adjusting the inclination it has been found possible to pump oil between the surfaces to a pressure of as much as 3,000 lbs. per square inch.

These experiments were originally instituted to demonstrate whether with similar lubrication and conditions a bearing surface composed of one alloy would allow of a greater load than a bearing surface of another alloy, and they have proved that it will not. The composition of the metal of the bearing surface has little or no influence on the load that the bearing will support. Bearings composed of a metal that may, under certain circumstances, seize at a pressure of 20 lbs. per square inch, have been run with a load of more than 3,000 lbs. per square inch, and many different kinds of metal have been used in bearings that have run loaded to more than 1 ton per square inch. At these loads the lubrication becomes so uncertain and difficult that the point at which it fails is due to conditions that cannot be observed. In no case was there the slightest evidence that this point was reached sooner with one alloy than it was with another, so long as the metal itself would support the load. The experiments leave no doubt that so long as a bearing runs fairly cool the surfaces of the shaft and bearing are separated by films of oil. If the number of films is small it is possible to have considerable heating without actual seizing, but if the films of oil are entirely absent the surfaces adhere or seize at once. The simplest example of this kind of adhesion is afforded by the abrasion of an iron surface by a piece of brass. The crystals of the iron tear out crystals from the brass. By burnishing the iron surface this tendency is reduced to a minimum, and by corroding the surface chemically it is increased to a maximum. If the pressure and speed are low, a great deal of brass can be torn from the high places of a bearing, especially if there is a good supply of oil.

When a bearing that has worn to a surface is allowed to rest upon the shaft without the intervention of a film of oil, and the crystals of the bearing adhere to the shaft, they must make an

elevation on the shaft that would prevent it being turned except by a force sufficient to lift the load on the bearing to the height of the elevation due to the crystals. This would concentrate the whole load on this elevation, with the result that more crystals would be dragged out. If the load is very great, say more than 1 ton to the inch on an 8-inch by 4-inch bearing, seizure has occurred with a suddenness almost startling; but the presence of oil in some parts of the bearing, and the lower loads used in practice, generally make the seizing more gradual.

A piece of iron will not leave a mark upon a surface softer than itself; it becomes coated with the softer metal. If the bearing is of a material of which the crystals are individually stronger than those of the shaft, the crystals of the shaft adhere to the bearing, which, being stationary, causes the crystals to be heaped up in one place instead of being carried round and spread over the whole circumference of the shaft. This is the reason that the seizing of a cast-iron bearing is often attended with such disastrous results, and there can be no doubt that the softer the metal of the bearing the safer is the shaft from injury from seizing. Many hundreds of experiments were made upon the machine with soft-metal bearings without injury to the shaft, but when similar experiments were attempted with hard-bronze bearings the shaft was several times injured and had to be turned.

It is possible under some circumstances to provide sufficient lubrication without intermission. When this is the case, the shaft revolves in oil, and it is surprising with what a small power a heavy load can be supported, and how small the destruction of the surfaces may be under these conditions, as shown in Table II of the Appendix. It is well known that even when the lubrication has been continuous the surface of the bearing has suffered considerably, and in some cases the surface of the shaft. If it is accepted that so long as a bearing works cool and shows no sign of seizing, the surface and shaft are separated by films of oil, it is at first sight difficult to see how either metallic surface can wear away. In some cases the oil contains grit which is carried between the surfaces and scratches them. It has been proved on the testing-machines that dust that will float in a quiet atmosphere is usually less in bulk than the thickness of the film of oil. Had this not been the case the experiments could not have been conducted where they were, as the machine was exposed to a considerable amount of floating dust.

The corrosive effect of the oil itself on the surfaces does not appear to have been hitherto recognized. It was first observed

when experimenting with a pair of bearings of pure lead upon the 10-inch shaft. Olive oil was used, but after passing through the bearing several times, it became black and thick. This oil, after filtration, was composed of 16 per cent. of oleate of lead, 9·57 per cent. of oleic acid, and 74·62 per cent. of olive oil and glycerine. Oil of the same quality was then run through bearings composed of hardened tin, which were found to be but little affected. Disks of the metals used in the manufacture of bearings were immersed in oleic acid, and occasionally drawn up out of the acid so as to be exposed to the air. Lead and zinc rapidly corroded away; copper was corroded, but to a less extent. Tin and antimony were not appreciably affected. Oleic acid appears to attack lead, zinc and copper with great avidity. Even if the oil is free from acid it becomes charged with oxygen from the atmosphere which oxidizes the surfaces, the oxide itself being immediately carried away by the oil. A great number of experiments showed that a bearing composed of an oxidizable metal, such as hardened lead, could be worn and scraped to a surface corresponding to the shaft in a quarter of the time required to produce the same effect on a bearing composed of hardened tin. For this reason a number of the special forms of bearing were made of hardened lead. Hardened zinc was tried in one instance, the bearing being tested by hydraulic pressure after the usual pressure-gauge holes were drilled, and oleic acid being used as a lubricant. The acid attacked the surface so rapidly that instead of improving it became worse as time elapsed. Oil was then used, but when the surface had arrived at the point of delivering it at pressure, it was found that the oleic acid had soaked into the pores of the metal and so corroded it that the oil oozed out all over the bearing at very slight pressure. The alloys of zinc are probably the most crystalline used for bearings, and there seems to be no doubt that the size of the crystals greatly affects the rapidity of chemical corrosion.

This open grain or crystalline structure occurs more or less in all bronze castings, and renders them more subject to chemical corrosion than would otherwise be the case with an alloy of copper and tin. The chief recommendations of bronze as a material for bearings are its high melting-point, and its capacity of resisting high compressions. The melting-point of the tin alloys is 500° F. The alloys of lead and of zinc vary more than the tin alloys, but their melting-points are not much higher.

With suitable lubrication bearings should run cool; if the temperature rises above 200°, the viscosity of the oil is so much

reduced that the bearing will probably seize. There is considerable difference of opinion as to whether a bronze bearing will behave better than a tin bearing under such circumstances. The bronze bearing will, if allowed to run after it becomes heated, almost certainly injure the shaft, but the tin-alloy bearing will run till the temperature reaches 500° without injury to the shaft. Higher temperatures than 500° are dangerous, and with proper arrangements ought never to occur.

The compression test deserves more consideration than it has hitherto received. Many of the alloys of tin and lead now used to line bearings have so low a compressibility that they yield under the ordinary pressures applied to bearings with the result that the metal squeezes into the oil-inlets and stops lubrication. This circumstance is no doubt responsible for much of the trouble that has been experienced with the use of alloys of this class. It is suggested that no alloy should be used until it has been demonstrated satisfactorily that its point of first yield is considerably above the greatest load or shock to which it will be subjected in use.

The method of making such a test is very simple. A bush 4 inches in diameter by $3\frac{1}{8}$ inches bore, giving an area of metal of 5 square inches, is cast on a chill and is placed in a hydraulic press. A line is drawn on the side with a pair of compasses set to about 3 inches radius. The bush is loaded by successive increments of $\frac{1}{4}$ ton, the load being taken off each time. When it is found that the line drawn by the compasses thickens the previous line, the metal has yielded. Even after this point, different alloys behave very differently, some taking a large increase of load to cause a yield of $\frac{1}{8}$ inch, others continue to yield very fast after they first start. It is possible to make an alloy of tin that will not yield in this way until loaded to 8 tons per square inch.

The Author's experiments suggest the following rule. The oil should be introduced into a bearing at the point that has to support the least load and an escape should not be provided for it at the part that has to bear the greatest load.

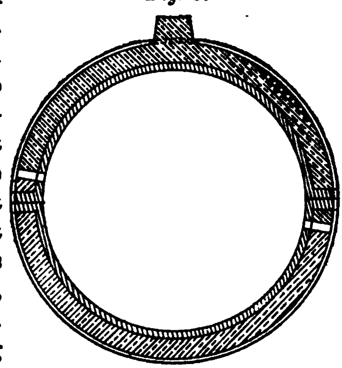
All the most important bearings belong to one of three classes—(A) those having a continuous load in one direction, (B) those having an alternating load in opposite directions, and (C), those with both a continuous load in one direction and an alternating load in opposite directions.

In class A is included the ordinary mill bearing or plummer-block used for supporting shafting. The oil is fed into the centre of the top bearing at the point that has to bear the least load, so that in this case the rule is conformed with. This class also

includes railway-carriage bearings. These were originally lubricated by holes through the crown of the bearing at the point of greatest pressure. It was, however, found that the lubricant would not enter at that point until the surfaces were more or less roughened. These bearings are now invariably lubricated according to the rule given. Footsteps of vertical shafts and thrust-blocks of marine engines belong to this class, but no experiments were made upon them.

In class B are included the bearings of vertical engines. The bearings of a marine-engine resemble the ordinary plummer-block, and in the shaft-tunnel their duty is the same; but those near the connecting-rod have an entirely different duty to perform, which is the same as the connecting-rod bearing. The oil is generally applied at the centre of the top bearing in defiance of the rule. If the oil-hole is left plain it is found that no oil will enter during that part of the stroke when there is pressure on the top half of the bearing. To meet this difficulty oil-channels are cut. It must be evident that as the pressure of oil between the surfaces gradually increases from the point of least pressure to a pressure equal to the load at the point of greatest pressure, channels that run circumferentially around the shaft must be bad unless they are confined to the part of least pressure. Their effect is to scrape off the oil at the point of greatest pressure, and deliver it unused at a point of less pressure. The result in the ordinary marine-bearing is that the oil delivered into the bearing runs down the channels as far as possible, and is not used on what might be called its first journey through the bearing. It is then taken up by the shaft and is carried to the second half of the bearing. The proper point to introduce the oil is just above the joint of the bearing at the side. There the oil is distributed over the shaft and carried to the point of greatest pressure. As there are no channels from this point the oil cannot escape, and will support almost any load. There is no reason why one bearing only should be lubricated in all large bearings; it is desirable that each half should have its own supply of oil (*Fig. 3*).

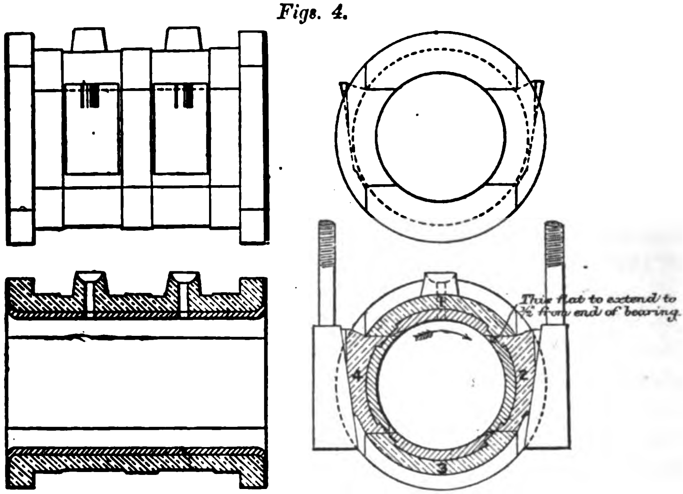
Fig. 3.



In class C are included the bearings of horizontal engines, espe-

cially the main bearing next the connecting-rod. This is the most troublesome kind of bearing, as it has double duty to perform. To facilitate the taking up of the wear the device shown in *Figs. 4* has been used. The bearing is in four parts, three of which can be drawn towards the centre. The oil is introduced at the top at a point of least pressure, but before it arrives at the first point of greatest pressure it has to jump a joint. At some parts of the stroke it cannot do this, as the load is too great, but at others it can, and it is then carried into bearing No. 2. Before it can reach No. 3 it has another jump greater than the last, because when the oil escapes here it cannot return. No. 3 receives very little oil, but No. 4 gets even less, as the pressure is never off No. 3, and

Figs. 4.



Scale, 1¼ inch = 1 foot.

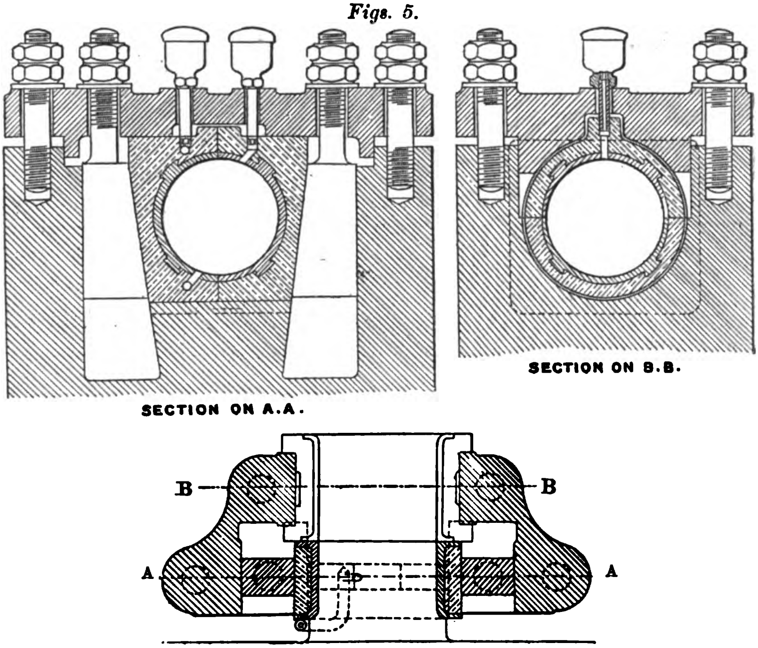
there is still another joint to jump. The only way of meeting the difficulty is to have two complete bearings. One of these would be jointed at the top and bottom, and would take the thrust of the piston, the other would be jointed in the opposite direction, and would take the weight of the shaft and fly-wheel. Such a bearing is shown in *Figs. 5*. It is very important that the oil should be fed at a point exactly central in the length of the bearing. If it is fed a little to one side the oil separates the surfaces and tilts the bearing, the consequence being that the oil is forced out at one end too fast, and at the other end the bearing is probably running dry.

The sides of a bearing should be carefully eased off, and should

slope toward the centre to bring the oil that escapes from the other half towards the centre. Channels in the bearing or shaft-surface can do no good except as receptacles for the débris when the bearing seizes. Such an advantage is very doubtful, but if they are used for this purpose they should be in a line with the shaft, and not pass round it. They must not extend more than three-quarters the length of the bearing.

When it is fully recognized that a bearing will sustain a load

Figs. 5.



Scale, 1¼ inch = 1 foot.

exceeding 1 ton per square inch, and that most costly and serious troubles are experienced with bearings that are loaded only to a twentieth of that load, it must be admitted that the subject requires investigation. The Author hopes that this Paper may in some small degree have the effect of suggesting new channels of thought and experiment that may add to knowledge on a subject of such great importance.

The Paper is accompanied by five drawings and two photographs, from which the *Figs.* in the text have been prepared.

[Appendix.

APPENDIX.

TABLE I.—RESULTS OF EXPERIMENT LVI.

Time.	Total Load on Top Bearing.	Temperature.	Total Tangential Pull.	Time.	Total Load on Top Bearing.	Temperature.	Total Tangential Pull.
Minutes.	Lbs.	° F.	Lbs.	Minutes.	Lbs.	° F.	Lbs.
..	5,376	98	..	80	32,906	230	470·0
10	5,376	113	80·0	90	37,632	242	400·0
20	7,706	116	115·0	100	42,470	245	350·0
30	12,723	128	155·0	115	42,470	242	400·0
40	16,934	134	157·5	125	42,470	262	400·0
50	19,264	154	215·0	135	42,470	264	400·0
60	23,834	220	400·0	145	42,470	258	350·0
70	27,552	182	350·0	150	47,846	280	470·0

Area of bearing-surface of top bearing = 2½ inches by 8 inches = 20 square inches; bearings lubricated with sperm oil. Diameter of shaft, 4 inches; speed, 266 revolutions per minute.

After having run for 150 minutes, bearing was taken out; its bearing-area was highly polished at the ends, and seemed to have seized at the middle.

EXPERIMENT LVIII.

The same bearings were used as in Experiment LVI, and they were lubricated with sperm oil and pads. The total load on the bearing was 15,132 lbs. = 756·6 lbs. per square inch. A vacuum gauge connected to the centre of the bearing showed a vacuum of 28·4 inches of mercury, the barometer standing at 30·2 inches.

TABLE II.

Time.	Temperature.		Load.	Tangential Pull.	Time.	Temperature.		Load.	Tangential Pull.
	L. H.	R. H.				L. H.	R. H.		
	°F.	°F.	Tons.	Lbs.		°F.	°F.	Tons.	Lbs.
7.30	127	127	18·96	115·5	12.0	145	139	18·96	95·0
8.0	136	132	18·96	115·0	12.30	146	139	18·96	95·0
8.30	138	134	18·96	115·0	1.0	146	140	18·96	95·0
9.10	96	96	4·6	60·0	2.10	98	98	4·6	95·0
9.30	128	125	18·96	110·0	2.30	130	130	18·96	105·0
10.0	135	131	18·96	102·5	3.0	134	134	18·96	100·0
10.30	138	133	18·96	100·0	3.30	137	137	18·96	95·0
11.0	140	137	18·96	100·0	4.0	138	138	18·96	95·0
11.30	143	138	18·96	95·0	4.30	140	140	18·96	92·5

Area of bearing-surface of top bearing = 18 square inches; bearings lubricated by pads hung on either side of the shaft and feeding neat's-foot oil by capillary attraction. Diameter of shaft, 4 inches; speed, 266 revolutions per minute.

(*Paper No. 2976.*)

"Determination of Crank Angle for Greatest Piston Velocity."

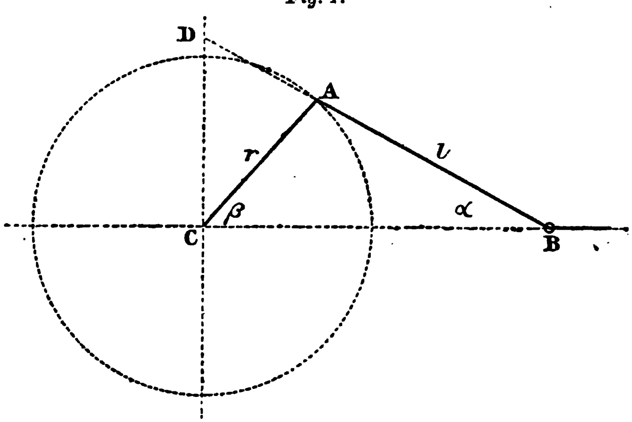
By WILLIAM CAWTHORNE UNWIN, B.Sc., F.R.S.

IF C A, *Fig. 1*, is a crank and A B a connecting-rod, and C D is perpendicular to the line of stroke, then, as is well known,

$$\frac{\text{Velocity of piston}}{\text{Velocity of crank-pin}} = \frac{C\,D}{C\,A}.$$

For nearly all the revolution C D is less than C A and the piston

Fig. 1.



velocity is less than the crank-pin velocity, but for two small parts of the revolution, when the direction of the connecting-rod is nearly tangential to the crank-pin circle, C D is greater than C A, and the piston velocity is greater than the crank-pin velocity.

It has been usual to assume that approximately the piston velocity is greatest when the crank and connecting-rod are at right angles. Let l be the length of connecting-rod, r the crank

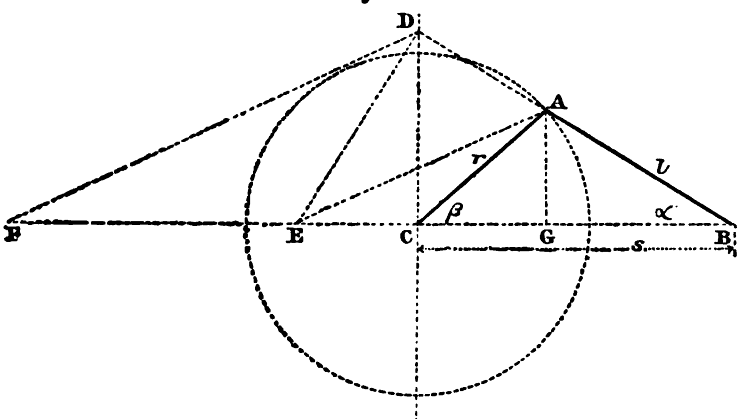
radius, and let $\frac{l}{r} = n$. The crank angle β, when the crank and connecting-rod are at right angles, is given by the relation—

$$\tan \beta = n \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and this determines approximately the angle for which the piston velocity is greatest.

The determination of the exact value of β for which the piston velocity is greatest is known to present some difficulty, and, so far as the Author is aware, the first exact solution has been found by Professor Hill.[1] The same result, however, may be reached by a different and, in some respects, an easier path.

Fig. 2.



In *Fig. 2*, let C A be the crank, and A B the connecting-rod as before. Produce A B to intersect a perpendicular to the line of stroke in D; draw D E perpendicular to D B, join E A, and draw D F parallel to A E, and A G parallel to D C. Let C A = r, A B = l, C B = s; let $\frac{l}{r} = n$; and let angle A C B = β, A B C = a.

It has been shown by Rittershaus[2] that the piston acceleration is proportional to F E − E C, the construction being now well known. The piston velocity will be a maximum when the acceleration is zero, and therefore at that position of the crank which makes F E = E C.

[1] Minutes of Proceedings Inst. C.E., vol. cxxiv. p. 390.

[2] "Machine Design," Part II, p. 72; Civilingenieur, xxv. s. 461; xxvii. s. 283.

From the figure—

$$E B = \frac{D B}{\cos a} = \frac{s}{\cos^2 a}$$

$$\frac{F E}{E B} = \frac{D A}{A B} = \frac{C G}{G B} = \frac{r}{l} \cdot \frac{\cos \beta}{\cos a} = \frac{\cos \beta}{n \cos a}$$

$$F E = \frac{s}{\cos^2 a} \cdot \frac{\cos \beta}{n \cos a}$$

$$E C = C D \tan a = s \tan^2 a,$$

when the piston velocity is greatest,

$$F E = E C$$

$$\cos \beta = n \sin^2 a \cos a \quad . \quad . \quad . \quad . \quad (2)$$

But

$$\sin a = \frac{\sin \beta}{n}$$

$$\cos a = \sqrt{\left(1 - \frac{\sin^2 \beta}{n^2}\right)}.$$

If these values are introduced, equation (2), squared, becomes—

$$\frac{n^2 \cos^2 \beta}{\sin^4 \beta} = 1 - \frac{\sin^2 \beta}{n^2}$$

$$\sin^6 \beta - n^2 \sin^4 \beta - n^4 \sin^2 \beta + n^4 = 0.$$

If

$$x = \sin^2 \beta$$

$$x^3 - n^2 x^2 - n^4 x + n^4 = 0 \quad . \quad . \quad . \quad (3)$$

a cubic equation, from which the exact value of β which makes the piston velocity a maximum can be determined. To find the roots, let

$$y = \frac{n^2}{3} - x;$$

then the equation becomes—

$$y^3 - \frac{4}{3} n^4 y + \frac{11}{27} n^6 - n^4 = 0 \quad . \quad . \quad . \quad (4)$$

Let $k = \frac{4}{3} n^2$ and from trigonometrical tables find an angle ϕ, such that—

$$\sin 3 \phi = \frac{27}{16}\left(\frac{11}{27} - \frac{1}{n^2}\right);$$

then the roots of equation (4) are—

$$\begin{aligned} y &= k \sin \phi \\ &= k \sin (60 - \phi) \\ &= - k \sin (60 + \phi). \end{aligned}$$

Of these roots the first only gives possible values of $\sin \beta$. This root gives—

$$\sin^2 \beta = x = \frac{n^2}{3} - k \sin \phi \quad . \quad . \quad . \quad (5)$$

an equation from which the required value of β is readily found.

From the general equation (3) the following extremely approximate and very simple expression has been found, which gives β with much less arithmetical labour—

$$\sin^2 \beta = \frac{n^2}{n^2 + 1} \cdot \frac{2 n^2 + 1}{(n^2 + 1)(n^4 - 4 n^2)} \quad . \quad . \quad (6)$$

Three methods of finding β are therefore available. The exact value is given by equation (5); the ordinary used approximation is given by equation (1); and a very much closer approximation by equation (6). The following short Table gives values of the crank angle calculated by the three equations for ratios of connecting-rod to crank ranging from 2 to 5:—

—	Values of β for $n =$ 2	3	4	5
	° ′ ″	° ′ ″	° ′ ″	° ′ ″
Exact value, equation (5) . .	67 41 59	73 10 30	76 43 24	79 6 32
Ordinary approximation, equation (1)	63 26 6	71 33 54	75 57 49	78 41 24
Approximation, equation (6) .	67 43 10	73 10 31	76 43 15	79 5 58

(*Students' Paper No. 373.*)

"Loughborough Sewage- and Refuse-Disposal Works." [1]

By Arthur Shaw Butterworth, Stud. Inst. C.E.

The town of Loughborough was constituted a Local Board District in 1850, and was incorporated in 1888. Its area is 3,045 acres, and it has a ratable value of £71,737, the population being about 20,000. It is situated in the valley of the Soar, within about 1 mile of that river, which, 12 miles higher in its course, passes through Leicester. The principal sources of industry in the town include hosiery manufacture, electrical construction works, bell-founding, dyeing, bleaching, and brewing.

A few years ago, the attention of the Loughborough Corporation was called to the fact that the discharge from the sewers within its jurisdiction was fouling the river, which forms for some distance the boundary between Nottinghamshire and Leicestershire, by the Councils of those two Counties, and immediate steps were demanded to efficiently purify the sewage, as required by the Rivers Pollution Act, 1876. The matter had already been under discussion by the Town Council, and the preparation of a scheme was entrusted to the Borough Engineer, Mr. Ambrose W. Cross, Assoc. M. Inst. C.E.

A sewerage system had been carried out in the town in 1852, the sewage being discharged in a crude condition into small tributaries of the Soar, at three different points, Fig. 1, Plate 6, viz.:—(A) Hermitage Brook, where the sewer invert was at a level of 119·25 feet above Ordnance datum; (B) Bottle Acre Brook, Ordnance level 122·55 feet; and (C) Woodbrook, Ordnance level 121·15 feet. A test was made on the broad-irrigation system, which conclusively proved that the sewage, after passing through 9 feet of soil, sand and gravel, still retained the dye-stain, and was not in a suitable condition to be discharged into the river. It was therefore decided to adopt a scheme which included chemical

---

[1] This communication was read and discussed at a Supplemental Meeting of Students on the 28th February, 1896, and has been awarded a Miller Prize, Session 1895-96.

precipitation in settling-tanks, with subsequent filtration through land. A suitable area, comprising 35 acres, was selected in a convenient position about 1 mile from the town, where the nature of the ground was most favourable, being very nearly level, and consisting of 1 foot 6 inches of soil, 4 feet of clean sand, and then gravel, gradually increasing in coarseness to a depth of 15 feet, where clay is found, and has been proved to extend to a depth of at least 40 feet. Although the district is liable to floods, this land is just above highest flood-level.

The present normal discharge of sewage in dry weather from the various outfalls has been gauged as follows:—

Name of Outfall.	Gallons per Twenty-four Hours.	Maximum Hourly Flow—7 per Cent. of Total.	Per-cent-age.
Hermitage (A) . . .	180,000	say 12,500	25
Bottle Acre (B) . . .	107,000	„ 7,500	15
Woodbrook (C) . . .	427,000	„ 30,000	60
Totals . . .	714,000	50,000	100

Taking the total maximum hourly flow of 50,000 gallons as a basis, an intercepting-sewer 21 inches in diameter was formed, with a gradient of 1 in 754·3, or 7 feet per mile, commencing at the Hermitage Outfall (A) at a depth of 8 feet 9 inches below the ground, and picking up the Bottle Acre Outfall (B), but at the interception of the Woodbrook Sewer (C) the diameter was increased to 24 inches, with a gradient of 1 in 586·6, or 9 feet per mile. This will discharge, when running one-half full, 97,185 gallons per hour, and when running two-thirds full, 147,881 gallons per hour; so that ample provision is provided above the present maximum dry-weather hourly flow of 50,000 gallons. The intercepting-sewer was constructed largely along the lines of proposed new streets. The subsoil water-line averaging only 3 feet below the surface, it was considered advisable to construct this sewer of iron pipes, in order to ensure absolute water-tightness, as the whole of the sewage would have to be pumped.

Storm-overflows are provided at the Hermitage and Woodbrook Outfalls (A) and (C); but as each of these outlets is liable to flooding, it was impracticable to fix the ordinary storm-overflow, consisting of a weir, at such a level as to come into operation when

the sewage had risen to a certain height. The connections, therefore, to the existing sewers, consist of earthenware pipes of such a diameter as will permit a volume of sewage equal to double the maximum dry-weather flow to enter the intercepting-sewer, the remainder being retained and passed direct to the brooks.

The sewage, on arrival at the purification works, Figs. 2 and 3, at a depth of 14 feet, is discharged into a screening-chamber D, which is fitted with a 5-foot by 3-foot 9-inch screen, at an angle of 60° to the horizontal, the bars being ½ inch apart. For cleansing the screen, Stott raking apparatus is used; it raises to the surface the sticks, paper, and other intercepted rubbish which would foul the pumps. This apparatus can be worked either at intervals by hand, or continuously from the main shaft in the engine-house. In the screening-chamber the chemical precipitant is added, so that it may become thoroughly incorporated with the sewage during its passage through the pumps. Numerous experiments have been made with the object of ascertaining the most efficient and economical material to use for this purpose, but no final decision has yet been arrived at, although several have been proved to be very effective.

The sewage has now reached the pump-well or storage-tank, an underground chamber 30 feet by 25 feet by 14 feet deep, with a capacity, up to the storm-overflow, which delivers into the main land-drain, of 50,000 gallons. As the sewage rises in this chamber, the intercepting-sewer is also storing another 50,000 gallons. The walls, consisting of 3 feet of 4 to 1 concrete backing with 9-inch blue-brick face (every fourth course of brickwork being 13½ inches thick to form a key with the concrete), are slightly curved outwards, in order to resist the external pressure of the ground and subsoil water, when not balanced by the pressure of sewage within the tank. The floor of the tank is in the shape of an inverted arch, to resist the upward pressure, five channels falling from the invert towards one side to drain the tank, and to form sumps for the pump suction. This tank has been constructed of sufficient capacity to temporarily store a suddenly increased discharge of sewage during an exceptional rainfall, for the storm-water and sewage systems of Loughborough are not separated, as is frequently considered advisable in modern practice. This tank is ventilated by a 12-inch connection to the chimney-shaft.

Over the pump-tank is the engine-house, forming part of a two-storey building, comprising chemical store, fitters' repairing shop, office, committee-room, tool-store, cart-shed, etc. The floor of the engine-house consists of 4 to 1 Portland-cement

concrete arches, averaging 2 feet thick, carried on the walls of the pump-tank, and three main 14-inch by 10-inch compound steel girders.

The pumping plant consists of a pair of Tangye horizontal condensing steam-engines, right- and left-hand, each of 26 I.HP., with 18-inch by 10-inch cylinders and 6-foot fly-wheel, with Soho governors and Meyer expansion gear, arranged to work at a pressure of 65 lbs. per square inch. Each engine is capable of driving the three 8-inch centrifugal pumps, while each pump, at a speed of 630 revolutions per minute with the lift of 24 feet, will discharge 40,000 gallons per hour. Provision is made for an additional engine and two additional pumps, which would give a total pumping capacity of 4,800,000 gallons per twenty-four hours. The sewage is discharged from the pumps at a height of 10 feet above the ground, and passes by a 24-inch cast-iron pipe under the high-level road to the commencement of the open carriers leading to the two Dortmund tanks.

The original scheme included the provision of three ordinary shallow precipitation-tanks of large area. It was considered advisable, however, to abandon these in favour of the Dortmund tanks,[1] Figs. 3 and 4. These are circular in plan, each 27 feet in diameter, 27 feet deep to the top of the cone, and 50 feet deep to the sludge-sump at the bottom. Suspended in the centre of each tank are a 5-foot and a 6-inch iron pipe. The sewage, on leaving the pumps, is discharged into an open concrete carrier, E, along which it is conveyed to the centre of one of the tanks, this carrier being supported by two compound 14-inch by 10-inch steel girders, between which concrete arches are turned. From these girders are suspended a cylindrical wrought-iron down-flow tube 5 feet in diameter, supported also by a girder at the base, down which the sewage is conveyed to the level of the top of the cone. At the bottom of the tube it is enabled to spread itself all over the area of the tank by eight ridge-shaped spreading arms, open on the under side, which are bolted to the down-flow tube, and bedded in the concrete of the cone wall. The sewage then rises up the tank outside the 5-foot tube, with a very low velocity, owing to the largely increased sectional area. Meanwhile the sludge is precipitated, and gradually sinks to the bottom of the cone F. The sewage having risen to its original level in the inlet carrier (or nearly so), overflows by the weirs, of which there are seven in each tank, each 4 feet wide, and fitted with semi-circular

[1] See also "Sewage Disposal," by W. Santo Crimp, p. 58.

scum-irons, 12 inches deep, into the circular carrier which surrounds the tanks. The inverts of all the inlet carriers, and of this circular outlet carrier, are level, and each outlet carrier is directly connected to the inlet carrier of the other tank, penstocks being placed at each junction. This is necessary in order to arrange that the tanks may be used in any of the following ways:—

(i) *Intermittent.*—One tank may be recharged with the foul sewage, while that in the other tank is in a state of quiescence, which of course will, in its turn, be expelled by the readmission of foul sewage down the 5-foot tube.

(ii) *Continuous*, (*a*) (*through one tank only*).—The tanks may be used, as it might be described, "in parallel," the penstocks, G, in each inlet carrier being open, and the sewage allowed to divide, half the volume passing through each tank. (*b*) (*through both tanks*).—They may also be used "in series," either tank being used first. In this case, the whole of the sewage is conducted to, say, No. 1 tank, having passed through which it is prevented from getting away by the outflow carriers by the closed penstock H, and passes along the carrier J, to the inlet carrier of tank No. 2, the penstocks K L being open, and M and N closed. From the overflow weirs and carriers it passes to the tumbling-bay O, and thence to the main distributing carriers, and thus to the land. If desirable, both tanks may be shut off, and the sewage permitted to overflow the weir P into the tumbling-bay Q, passing along a line of 24-inch pipes to the tumbling-bay O.

A 6-inch cast-iron pipe R runs down the centre of each tank to within about 1 foot of the bottom of the sludge-sump F. At the top of the tank this pipe is carried through to the outside of the embankment, and is fitted with a sluice-valve, the delivery being about 6 feet below the level of the sewage in the tank. When the valve is opened, the pressure of water in the tank forces the liquid sludge from the sump up the pipe, and delivers it automatically about 4 feet above the ground. At present it is conveyed to a specially-drained area, and is afterwards used for filling hollow places in the land; a large amount being also disposed of as manure. Each of these tanks has a capacity of nearly 100,000 gallons, as measured to the top of the cone, so that, with the average hourly flow of 30,000 gallons, there will be an average of six hours' quiescence, or its equivalent, when both tanks are in use.

It was originally intended to sink the walls of these tanks on a

cast-iron curb, with a tubbing of cast-iron plates, bolted together; but this method was abandoned owing to the possibility of unequal settlement, or of the wall becoming earth-bound. Annular trenches were excavated, 6 feet wide, down to the foundation of the tank walls, which ran about 4 feet into the clay. The walls were then built up to ground line, consisting of 9-inch blue-brick face, with 2 feet of 4 to 1 concrete backing. The centre piece, or "dumpling," was then excavated, a shaft 7 feet by 7 feet sunk, and the cast-iron sludge-sump fixed. The body of the cone was then excavated, and the walls, consisting of 2 feet of concrete, inserted, and faced perfectly smooth with cement rendering. This was preferred to brickwork in order to obtain a very smooth surface, so as to prevent, as far as possible, the adhesion of sludge to the sides of the cone, which are battered to an angle of 60°. The tanks above water-line are lined with brown glazed bricks, as also are all the tumbling-bays, &c. During the construction of these tanks, a large amount of water was met with until the clay was reached, which was practically dry, no faults being found.

The principal advantages of this type of precipitation-tank are:—(i) A comparatively small area of land is required to provide a large tank capacity. (ii) The cost of construction is considerably less than that of the old-fashioned shallow tanks of the same capacity. (iii) A smaller surface of sewage is exposed to the sun in summer. (iv) Owing to the method of withdrawing the sludge, it is unnecessary to have a spare tank in order to drain off the sewage and collect the sludge. (v) The sludge is delivered above the ground without any manual labour, or the necessity of pumping the sludge.

After passing through the tanks, the fairly clear resultant effluent is distributed on the land by main carriers, constructed of concrete *in sitû* with cement-rendered face, and provided with penstocks at intervals, and earthenware blocks with 6-inch flap-valves, delivering into earth channels, cut as required. The works have not yet been in operation sufficiently long to enable any definite conclusion to be arrived at as to the value of any crops which may be raised. A portion of land alongside the brook will be devoted to osiers, so that it may be flooded to a considerable depth if desired.

At an average depth of 5 feet 6 inches, and 150 feet apart, 9-inch land drains are laid, consisting of earthenware socket-pipes, with a strand of tarred yarn only in the joints to exclude the fine sand, this object being also attained by surrounding the pipes

with turf and surface soil. At intervals 4-inch junctions are fixed, in case of extra land-drainage becoming necessary. These 9-inch drains discharge into the main 24-inch land-drain, which conveys the well-filtered and pure effluent down to the River Soar, open manholes being carried above the ground for the purpose of supplying fresh air for the aeration of the effluent.

Analyses of the sewage and effluent by Mr. S. F. Burford, F.C.S., are given in the following Table:—

—	Crude Sewage.		Effluent.	
	Grains per Gallon.	Parts in 100,000.	Grains per Gallon.	Parts in 100,000.
Solid matters in suspension	154·0	220·0	0·56	0·8
„ „ „ solution	60·2	86·0	62·79	89·68
Chlorine	4·8	6·86	4·39	6·27
Free ammonia	1·701	2·430	0·273	0·39
Albuminoid ammonia	2·345	3·350	0·1645	0·235
Oxygen absorbed in fifteen minutes at 80° F.	4·8011	6·859	0·1234	0·1763
Oxygen absorbed in four hours	12·2556	17·508	0·1967	0·281

The total solids in suspension and solution in the tank effluent as discharged on to the land are ninety-five parts in 100,000. The sludge as drawn from the 6-inch sludge-pipe contains 88·33 per cent. of water.

The steam necessary for pumping the sewage is entirely raised by the burning of the ashpit refuse of the town. This is equivalent to an annual saving of £400 or £500 as compared with the cost of coal. It would scarcely be just to set the expenses of burning the refuse against the cost of coal, as the cost of refuse disposal would be the same, if conducted independently. Although a certain amount—generally a very small percentage—of the heat produced in the process of refuse disposal in furnaces is utilized in some towns, it seems to be a general opinion amongst engineers that the refuse of a town is of no, or very little, substantial calorific value. The Author has strongly maintained that the steam-raising power of the refuse of some towns was worth consideration, and this has proved to be true at Loughborough, as subsequent figures will prove.

The refuse-destructor is situated at the end of the buildings, and is approached by a high-level road which runs at a uniform

level from the canal bridge—thus avoiding a double incline—and round the front of the buildings, at a height of 13 feet, an inclined road leading down to the low level at the rear. This road has been constructed entirely of the ashpit refuse of the town, manufacturers' ashes, and builders' rubbish, well rolled and consolidated, the banks being soiled and turfed. Each road is 15 feet wide, and fenced with iron railings. The destructor, Fig. 5, is of novel design, and was constructed by Messrs. H. Coltman and Sons, Loughborough.

In destructors, where it is attempted to utilize the heat, a multitubular boiler is generally placed in the flue between the furnace and the chimney. Only a small portion of the available heat is thus utilized. This furnace has been designed with the object of collecting the direct heat of the furnace itself, as well as that of the escaping gases. The refuse is tipped from the carts into a hopper, *a*, from whence the furnace is charged by hand down the shoot, *b*. The arrangement of the furnace consists of a water-tube boiler, each of the lower shells being 12 feet by 4 feet 6 inches, and the upper 12 feet by 5 feet 6 inches, these being connected by continuous water-chambers, *c*, and one hundred and ten 2¼-inch tubes, eighty-eight outside the water-chambers and twenty-two in the furnace proper. Between the two bottom shells is the fire-grate, having an area of 28 square feet, consisting of Perrett bars, 9 inches deep, of the shape shown in the Figs., the lower 4½ inches dipping into a water-bath, the level of which is preserved by a cistern and ball-valve. This arrangement keeps the bars cool and prevents the clinker from adhering to the bars; while a forced draught from a 12-inch fan, driven by a special 3 HP. horizontal engine, is introduced above the water-surface, and maintains a high temperature. The bars, being only ⅛ inch apart at the grate surface, and the strong upward blast, prevent the dust from falling through; thus a good hard clinker is formed, which is easily removable, and is used for miscellaneous purposes.

In order to avoid the chilling effect of the surfaces of the boiler upon a newly-spread fire, fire-brick blocks, *c*, easily renewed, are carried on pockets riveted to the bottom cylinders of the boiler, which become white-hot, and radiate upon the green refuse freshly drawn forward. These blocks run continuously in the form of an arch from the back of the furnace to within 18 inches of the front. The whole boiler is enclosed in a fire-brick arch. When the furnace is freshly charged from the hopper, the gases from the green refuse have to pass directly over the hottest part

of the fire to the front of the furnace; then up, at *d*, between the end of the fire-brick blocks and the furnace front, and back to the rear along the central flue, *e*, in contact with all three shells. The water-chamber, and the inner tubes, then pass round the rear end of the continuous water-chamber, and back along the flues, *f f*, catching other portions of the shells, the water-chamber and the outside rows of tubes, down to the flues *g*, being in contact with the bottoms of the two lower cylinders. Thence the gases may pass direct to the chimney by the main flue, the chimney being octagonal and 80 feet high, and of an average internal diameter of 4 feet; or they may be diverted and passed through the supplementary multitubular boiler, 10 feet by 4 feet 6 inches, which is ordinarily thus used as a feed water-heater for the destructor boiler proper, but is capable of raising sufficient steam from coal fuel to drive the engines when the destructor is thrown out of work, for boiler inspection purposes. Thus there is every opportunity of utilizing all available heat to the fullest extent. At present only one cell has been erected, but it is more than capable of accomplishing the desired work and of burning much more than the average 8 tons of refuse per day available. The works are now entirely lit by electricity, the necessary steam being provided by the destructor.

Exhaustive tests of ten hours' duration have been made by Messrs. Coltman in the presence of and certified by the Borough Engineer of Loughborough, or the Author. The refuse was tipped direct from the carts and was entirely unscreened. The following results were obtained:—

Refuse burnt per twenty-four hours	15 tons 14 cwt.
Weight of resultant clinker	3 „ 14 „
Amount of clinker	24 per cent.
Water evaporated (from feed at 36° F. raised by multitubular boiler to 150° F.) per lb. of refuse burnt	2·02 lbs.
Water evaporated from 212° per lb. of refuse burnt	2·38 „
Steam pressure	65 lbs. per square inch.
Power available	98 I.HP.
Temperature in furnace and first flue	2,500° F. (copper and steel fused).
„ „ bottom flue at front	970° F. average.
„ „ main flue of gases leaving destructor	590° „
„ of gases leaving multitubular boiler to chimney	215° „
„ „ feed-water	36° „
„ „ „ after multitubular boiler	150° „
Water evaporated in tank under bars	6 gallons per hour.
Air-pressure under bars	1½ inch of water.
Portion of steam consumed by fan	3 per cent.

The scheme has been carried out within the original estimated cost of £20,000. The actual cost has been as follows:—

	£.
Purchase of 35 acres of land for works	4,000
Compensation to owners and tenants, wayleaves	1,000
Legal expenses, stamps, fees, &c.	1,200
Intercepting-sewer and connections	4,400
Effluent discharge, land-drains, carriers and land preparation	2,200
Storage-tank and buildings, retaining-wall and bridge	1,800
Dortmund tanks	1,800
Destructor and chimney	1,400
Engines, pumps, and dynamo with fittings	900
Miscellaneous direct payments, labourers' wages, tradesmen's accounts, &c., including high-level road	1,100
Balance in hand	200
Total	£20,000

The Author had charge, under the Borough Engineer, of the preparation of plans and drawings, and afterwards of the field-work; and supervised the execution of the various contracts.

The Paper is accompanied by a tracing, from which Plate 6 has been prepared.

(*Students' Paper No. 376.*)

"Iron Tunnels."[1]

By William Orr Leitch, Jun., Stud. Inst. C.E.

The extraordinary increase of traffic in cities, and the demand for direct communication by the shortest route, have led to the construction of railways under the busiest streets, running close to the most valuable property, and passing on their way the maze of sewers, gas- and water-pipes, existing underground railways, under rivers, and through difficult and varying strata, in order to gain for the community, and possibly to snatch from a rival route, all the advantages of the most rapid transit. These conditions have led to the introduction of iron tunnels, driven in cities far below all obstruction, and from an operating base so as to involve the least interference with the street surface. For crossing under rivers and penetrating loose and water-bearing strata the design is specially suitable, as, after the material has been excavated, the tunnel is quickly built, and at once attains its maximum strength.

The use of the shield and artificial air-pressure has largely aided the success of such works. In 1816 Sir Isambard Brunel, when studying the operations of the *teredo navalis* on an old ship's timber at Chatham, originated the idea of using a shield. His daring method of attacking the construction of the celebrated Thames Tunnel in 1825, and the extraordinary difficulties met and overcome from that time till the tunnel was opened in 1843, are well known.[2] The form and details of the shield have since been altered and improved, but the principle of a protecting and attacking machine ever moving on with the advance of the works is maintained, and it is not a little remarkable that Brunel's was by far the largest shield that has yet been made. It covered a face 38 feet wide, and 22 feet high.

---

[1] This communication was read and discussed at a Supplemental Meeting of Students on the 17th January, 1896, and has been awarded a Miller Prize, Session 1895–96.

[2] "A Memoir of the Thames Tunnel," by Henry Law, Weale's Quarterly Papers on Engineering, 1845, vol. iii., and 1846, vol. v.; and "Memoirs of the Life of Sir Marc Isambard Brunel," by Richard Beamish, F.R.S., pp. 202–281.

The use of artificial air-pressure, largely taken advantage of in iron-tunnelling, was the subject of a patent by Lord Cochrane in 1830 [No. 6,018]. It was first used twenty years later in sinking bridge-foundations, and not till 1879 was it applied to horizontal boring at a small tunnel at Antwerp, and at the Hudson River Tunnel, New York. Lord Cochrane expected that the pressure would not only keep back water, but would perform the upholding work of a shield. He did not foresee that it is impossible to exactly balance the incoming pressure, as the head is greater at the bottom of the tunnel than at the top. This difficulty is much increased in large tunnels, and in cases where the height of the tunnel is considerable in relation to the total depth. A number of examples will be given later in dealing with the effects of air-pressure.

The first iron tunnel, constructed of flanged plates bolted together in the form of a circle, was the Tower Subway under the Thames. It was bored by a small shield pressed forward by hand-screws, in 1869, and was designed by the late Mr. Peter Barlow to carry out his scheme of relieving the traffic of the streets. The size was very limited, and its purpose is now superseded by the opening of the Tower Bridge. It will always, however, be of historical engineering interest, as being the oldest iron tunnel.[1]

A number of iron tunnels have since been built, the principal of which are:—

Name.	Finished.	Outside Diameter.	Purpose.
		Feet.	
City and South London . . .	1890	11	Electric railway.
St. Clair	1891	21	Ordinary ,,
Mersey.	1892	10	Vyrnwy supply-pipes.
Edinburgh	1894	18½	Ordinary railway.
Clichy[2].	1894	8¼	Sewage disposal.
East River (Gas)	1894	10⅜	New York gas-pipes.
Glasgow Harbour	1895	17	Cross river road.
Waterloo and City	Building	13¼	Electric railway.
Blackwall	,,	27	Cross river road.
Glasgow District	,,	12	Cable railway.
Hudson River.	Unfinished	19½	Ordinary railway.

Short lengths at Kingston and Blackton reservoir and street

[1] "On the Relief of London Street Traffic, with a description of the Tower Subway," by P. W. Barlow, London, 1867 (Library Inst. C.E. Tract 8vo. vol. 270), and Minutes of Proceedings Inst. C.E., vol. xxix. p. 288, and vol. cxxiii. pp. 56 and 75.

[2] Since this Paper was written another tunnel slightly smaller than that at Clichy has been begun under the Seine. See "Le Génie Civil," 7th March, 1896.

sewers 4½ feet in diameter have also been built on the iron tunnel method. The total length of the principal works is about 16 miles of single tunnel.

General Methods of Construction.

The general methods of construction are the same for all iron tunnels. In large examples, however, special methods of attacking the excavation and erecting the plates are required. Ordinarily air-pressure is used, and, the whole of the operations being conducted from one base, a large and costly plant must be provided.

The principal machinery consists of the air-compressing plant. There are many kinds of compressors, but nearly all consist of a combination of steam- and air-cylinders working in tandem, the steam piston working the piston of the air-cylinder, which compresses at each stroke the quantity of air in front of it just before the commencement of the stroke. The air is admitted to the cylinder by tappet- or clack-valves, and sometimes by a slide-valve arrangement. The latter, however, interferes with the water-jacket, which is usually placed round the air-cylinder. Unlike the case of a mill or factory, where there are regular stoppages during which small repairs can be carried out, the air machinery must be kept steadily at work. No engine, however, can work continuously, and there should always be some reserve of power. If, therefore, the plant does not consist of two or more sets of engines, a favourite form of compressor is the double one, each side of which can be worked, either in combination with or quite separately from the other, as may be required, so that one side can be stopped altogether for an overhaul while the other side continues to work. The smallest air-compressor known to the Author as having supplied air to an iron tunnel is one that might be regarded as a model. It was only 9 feet long, and could be moved in one piece. The diameter of the steam-cylinders was 12 inches, of the air 15 inches, and the stroke was 12 inches. This engine supplied air to a 12-foot tunnel passing through clay. The escape or loss of air was therefore small, and the required pressure of between 10 lbs. and 15 lbs. per square inch was easily maintained. If, however, the tunnel had passed through more open strata, the escape would have been greater, and an engine having 24-inch and 30-inch cylinders and 30-inch stroke would have been rendered necessary. If more than one tunnel is being driven from the same base, or if the tunnels are large, several sets of engines having cylinders reaching 30 inches in diameter and 4-foot stroke have

to be used. The whole plant depends on the porosity of the ground, and the liability to loss of power by escape of air from the tunnels. This cannot be exactly ascertained except by actual trial, and the plant is often increased as the necessities of the progress of the work require. From the air-cylinder the air is led in pipes to the receiver, which acts as a reservoir from which the tunnels are supplied with air at a uniform pressure, and not varying with the speed of the engines. In the receiver (which is very often an old boiler) the air is cooled either by running cold water over the outside of it, or through it in tubes as in a condenser. If the pressure is high, and there is little escape in the tunnels, the heat there becomes very oppressive, frequently rising to 100° F. With effective cooling, on a summer day, with the temperature outside nearly 80° F., and the air at 15 lbs. per square inch pressure in the tunnel, the Author has known the temperature there to be kept at 65° F. This is very important for preserving the health of the workmen. In addition to the main engines, electrical machinery, small compressors for the grouter, and the feed-pumps, complete the engine-room outfit. If large hydraulic power is required at the shield, an installation has also to be provided to obtain this pressure, plant for which has been designed and used, raising the pressure as high as 5,000 lbs. per square inch.[1] Similar pressures are used for very large shields. Near the machinery a battery of boilers supplies the necessary power, and in connection with these it is advisable to have one or two large water-tanks if the supply is from a main, as these pipes are sometimes shut off for repairs.

A typical city shaft was the St. Enoch Square base on the Glasgow District Subway. It was fixed at the site of one of the future stations, which like all others on this railway is sufficiently near the surface to be accessible without lifts. A neat brick building with galvanized-iron roof contained the two double compressors; one, made by the Anderston Foundry Company, had 24-inch steam- and 30-inch air-cylinders, and 24-inch stroke. This engine occupied a space of 17 feet 6 inches by 9 feet, and weighed about 20 tons. The air was admitted to the air-cylinders by a slide-valve arrangement, and there was no water-jacket. The other was a Slee engine, having 24-inch steam-, and 26-inch air-cylinders, and a stroke of 3 feet. In it the air was admitted by clack-valves, and the cylinder had a water-jacket. These engines

---

[1] "East River Gas Tunnel," by W. I. Aims. Journal of the Association of Engineering Societies, U.S.A. May, 1895.

worked to about 70 revolutions and 60 revolutions per minute respectively, steam at 80 lbs. per square inch being supplied from three 26 feet by 7 feet Lancashire boilers, provided with Vicars mechanical stokers and smoke-consuming apparatus. A thin cloud of white vapour was all that escaped from the chimney. A double pit-head frame and winding-engine, and a temporary wooden stair gave access to the station below from which the tunnels were driven. Most of the stores were kept in a temporary flat erected in the station roof, and if the street space above had been further restricted, some of the machinery could have been placed down below also. Four 12-foot tunnels were driven from this station.

Another type of operating base is that of the Waterloo and City Railway at Blackfriars Bridge, which is built on a pier in the Thames. At one end is a battery of locomotive boilers, and a large double Markham air-compressor with 4-foot stroke. Here also is the plant for generating the electric power, which is much used on this work both for lighting and haulage. Two shafts descend from the centre of the pier, through the river-bed, down to the line of the tunnels beneath, and from these all the work is carried forward. Four steam travelling-cranes, running on rails along the side of the pier, command the whole stage, the shafts, and the lighters which take away the spoil and bring the segments, coals, and other stores. This proves a most efficient arrangement, involving the minimum handling of material. At the other end of the pier are the offices and stores. A gangway connects with the shore, but as much advantage as possible is taken of river carriage, and it is principally used by the men going to and from their work.

A very large plant is that laid down for driving the Blackwall Tunnel. There are six sets of compressors of the largest size, and a wharf in connection with the works provides the advantages of river-carriage.

Usually air-pressure is required for driving an iron tunnel, unless there is no doubt about the ground, such as when it is hard clay. To maintain the pressure in the tunnels, a bulkhead is built across the entrance, and communication made through an air-lock. The bulkhead is often made of brickwork, between 6 feet thick in small and 12 feet thick in large tunnels. In this is placed a steel tube between 12 feet and 17 feet long, and between 5 feet and 7½ feet in diameter. The ends may consist of cast or riveted frames and doors, in each case a strip of rubber round the edge keeping the door air-tight when shut. One door is always shut, and only one can be opened at a time. For passing through materials only, 2-inch taps, controlled from the outside, are

used to work the lock, while for the workmen, who, for medical reasons, must pass through slowly, a $\frac{3}{4}$-inch tap is provided, which can be worked from the inside. Sometimes the bulkhead has been made of steel plates, and again entirely of brickwork, with a passage through the centre, having doors fixed on frames let into the brickwork. An electric signalling apparatus, or, better still, a telephone, should be available for the working of the lock and communicating direct from the working face to the office and engine-house. Besides the main lock, provision must be made in the bulkhead for a number of pipes. The most important is the main pipe for supplying the compressed air. The smaller pipes consist of the air- and water-supplies to the grouter and the hydraulic-power pipes. Lighting and telephone wires, a pipe to the pressure-gauge, and a large pipe for passing through rails, planks, &c., should also be provided.

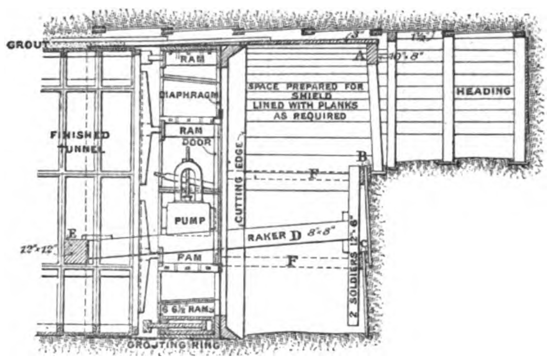
Ordinarily one lock is sufficient, but if the tunnel is large, two are used to facilitate the working, and frequently a small lock is placed near the top of the bulkhead, should there be any risk of access to the lower locks being barred. The inside door of this lock should be left open to the tunnel. In the lock ends blank flanges are left for any extra pipes that may be required, and often a bull's-eye pane is let into the door to facilitate working the lock. For hauling the materials inside to the lock, winches worked by compressed air or steam have been tried, the latter exhausting outside. Ponies have been used, but it was found that in high pressures mules and donkeys took much more kindly to the new conditions. Electric haulage is one of the features of the construction of the Waterloo and City Railway tunnels. A temporary floor is laid in the tunnel for the purposes of construction, and the hutches used are so small that empties can be easily tipped off the rails to allow the full hutches to pass at any point.

The chief difference between the usual method of constructing an ordinary tunnel and of iron tunnels is the employment of a shield, which consists of a cylindrical tube, surrounding and projecting in front of the end of the tunnel, from and in which the construction is carried on. There are two distinct types, the shield which requires to be supplemented by advanced timbering, if soft ground is met, and which is referred to as the assisted shield, and the independent shield which does not. The first is principally a protective agent; the latter is also an excavating machine. The object to be attained is to execute the minimum amount of excavation, and at the same time hold up the working-face so that no subsidence may take place. It is difficult to determine at what

point the necessity for a shield begins. In one or two instances the ground passed through became quite hard, and the shields with which the tunnels were started were taken out. For passing under rivers, however, and for driving through soft ground and near heavy buildings, the shield is a most valuable aid in constructing the tunnel.

The assisted shield is shown in *Fig. 1.* In it the diaphragm is at the front, rendering it very suitable for penetrating hard ground, as it gives great strength to the cutting end of the shield, which, without it, would be bent by any obstruction. To it also spikes can be fixed, which help to break down the ground in front. The position of the diaphragm, however, renders it impossible to force the shield ahead until the ground in front has been cleared away.

Fig. 1.



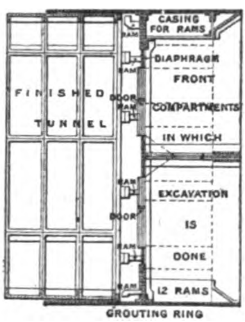
Scale, ⅛ inch = 1 foot.

Assisted Shield.

This is easy in hard ground, a few planks and props only being required to support the roof of the excavation until the shield is brought forward. On passing into soft ground, such a proceeding would result in the material falling down in front of the shield, and no progress would be made. Consequently the roof and face of the excavation, and sometimes even the sides have to be supported by a system of timbering if this type of shield is used. It is necessary to advance a timbered heading, *Fig. 1*, in which to erect a strong support A, resting on which at the front end and on the cutting-edge of the shield at the back end are placed 3-inch planks close together. The heading is then opened out in circular form, the excavation still being lined with planks until the top third of it is taken out, when a horizontal

setting of timber B is placed across the face and propped off the shield by the temporary props F. The middle third of the excavation is then poled and lined in the same way, another horizontal setting inserted at C, which is also propped off the shield, and so on down to the bottom of the excavation. The amount of timbering necessary depends entirely on the nature of the ground, its sole use being to preserve the excavated space till the shield can be brought forward. In order to do this, two upright timbers, called "the soldiers," are placed against the face, and by two raking struts D led through the open door of the shield, and butted on a cross beam E fixed in the tunnel, the shield, which previously held up the face, is relieved, and is now free to be pumped ahead into the space which has been made for it. The excavation is not taken out to the full diameter of the tunnel, but 1 foot of material is left, to be pared off by the advancing edge of the shield. That is only done below the plank lining. This assisted-shield method has several drawbacks in soft ground. The excavation is increased, as all the planks, &c., are outside the line of the tunnel. It is costly in timber, as much is left behind and lost, after being of use only for an hour or two. In risky circumstances the door of the diaphragm is open, as all work is in front, and for a part of the time, at any rate, cannot even be shut for the raking struts that support the face.

Fig. 2.



Scale, ⅛ inch = 1 foot.

INDEPENDENT SHIELD.

The independent shield has not these drawbacks, and should be used in soft ground. In fact, the assisted-shield method is hardly the shield method, but a combination with timber. The independent shield, *Fig. 2*, has the diaphragm near the middle, and by means of its powerful rams is forced into the material ahead, which is then excavated under shelter of the shield itself, and no timbering or working in front of and outside of the shield is necessary. This type of shield is built of plates and angles, and the front part is divided, by very strong horizontal and vertical divisions, into compartments, access to which is gained through doors in the diaphragm. In the assisted shield the pressure for working the rams is raised by hand-pumps, one on each side of the shield, the best method when a high pressure is not wanted. In the independent type more power is required, and the pressure is raised by

accumulating power, and is conveyed in pipes to the shield. A battery of cocks then controls the operating of any or all of the rams. In the assisted shield the rams are few in number, and press against the finished tunnel by arms on the end of the piston. The independent shield has double the number of rams, and double the pressure of an assisted shield. The pistons have no arms, and the end is bevelled off so that they press, not on the flange of the plates which might be injured by the heavy pressure, but against the body of the plates. In large tunnels shields of the independent type are used, varying in detail, with the risk of the ground tunnelled through giving way. At the St. Clair Tunnel, passing through clay, the front part of the shield was divided by two horizontal and three vertical partitions into nine working compartments, from which the excavation was taken. Between these compartments and the diaphragm was a space, round the circumference of which the rams were placed. At the bottom of the diaphragm were two doors which were always open, but which could be quickly closed. It was found, however, that the shield continually pressing on the clay in front did all that was required, and it was not found necessary to close the doors.[1] At the Blackwall Tunnel, where the material is water-logged ballast, greater precautions had to be taken. The front part of the shield is divided into four floors and twelve working compartments. By a system of iron shutters these can be entirely closed at the front and the risk of an inrush of material reduced to a minimum. The diaphragm is double, and the passages through it can be used as air-locks if required. A higher pressure can be applied in front than behind, and at the bottom than at the top of the shield. At the Mersey Tunnel the shield was also of the independent type, and had a curved diaphragm 2 feet back from the cutting-edge at the side, and 3 feet at the centre. There were no divisions in front, but a trap arrangement behind the diaphragm prevented any rush through the opening which was at the bottom.[2] The East River Gas Tunnel shield had four front divisions, and four doors in the diaphragm. It was rammed into the soft mud ahead, and actually rendered it more compact and easier of removal.

---

[1] No official account of the St. Clair Tunnel has been published. For more information than is contained in the short references in this Paper see *Engineering News*, New York, vol. xxiv. pp. 291, 425, 457 and 498.

[2] For an account of this work see Report of the British Association for the Advancement of Science, 1892, p. 532, "Shield Tunneling at the Vyrnwy Aqueduct Tunnel," by G. F. Deacon, M. Inst. C.E., and Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 100.

This shield could exert a forward pressure of 600 tons; in the large tunnels, such as St. Clair and Blackwall, the ordinary available force was about 3,000 tons. The Hudson Tunnel shield is another example of the independent type.[1]

When preparing the Paper the Author sketched a system of face-girders for small shields in soft ground. Instead of the divisions at the front of the shield, horizontal girders placed across the face and operated on by the rams were proposed. These would assist to excavate, and hold up the face of the excavation. When pressed to the front of the shield they were to be held in place when the whole shield was being moved ahead by their rams, which, projecting through into the tail of the shield, would be butted off the iron rings by means of adjustable screws on their ends. The Author has since learned, however, that a better arrangement on a somewhat similar principle was previously designed by Mr. Greathead. The next development in shields will no doubt be mechanical excavation, and continuous holding up of the face coupled with speedy working.

The building of the iron ring inside the tail of the shield presents no difficulties in small tunnels, a block and tackle hooked on to the top of the last completed ring being all that is required, as the plates are light. In large tunnels, however, the plates are not so easily handled, and very ingenious hydraulic-cranes, swinging on the diaphragm of the shield, pick up the plates and thrust them into place at any part of the circle. All that is then necessary is the grouting. When the shield leaves the tunnel behind it leaves a space equal to the thickness of the skin of the shield plus the clearance between the shield and the iron ring. If the ground is self-sustaining this space remains and must be filled. The grouting apparatus, one of Mr. Greathead's many ingenious appliances, consists of a cylindrical pan, in which the grout (usually a lime) is mixed, and then injected through a flexible hose through holes in the iron plates till no more can be forced in. The pressure is raised by a small 6-inch engine to about 40 lbs. to 50 lbs. per square inch. This invention is of very great value for filling otherwise inaccessible places.

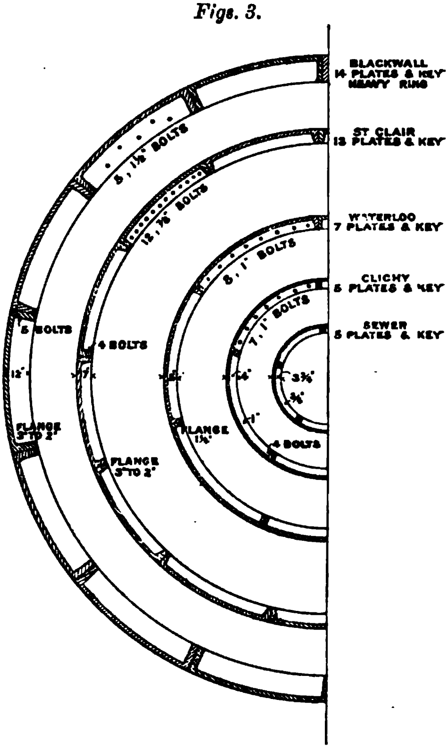
---

[1] *Engineering News*, New York, vol. xxiv. p. 54, 1890. Original method described by S. D. V. Burr in "Tunneling under the Hudson River," New York, 1885.

THE IRON RING.

The internally flanged cast-iron plates, of which the iron ring is constructed, have this advantage over brickwork, that the thickness of the shell is very small, and can be made very strong with a minimum ratio of total excavation to the net area ultimately available. The circular shape of the ring enables the most efficient type of shield to be used. In ordinary circumstances, however, the brick tunnel would perhaps be cheaper. The segments are now manufactured by high-class machinery, and the quality of iron is such that the tests give 6½ tons to 8 tons tensile strength per square inch. Bars on 3-foot bearings, 2 inches by 1 inch or 1 inch square must support 28 cwt. and 7 cwt. respectively. One of the principal seats of segment-making is at the works of the British Hydraulic Foundry, Glasgow, where special machinery has been erected for the casting and planing of the plates. Mr. E. G. Carey, Assoc. M. Inst. C.E., has described the machinery and process of constructing the plates at the above works.[1] In the latest examples of iron rings the plates are made long, and the horizontal joints are planed so as to give the maximum rigidity. Half sections of the rings at Blackwall, St. Clair, Waterloo, Clichy, and a small drainage tunnel, are shown in *Figs. 3.* The plates vary between 6 feet and 5 feet in length, except for the smallest; the flanges vary in depth between 12 inches and

Figs. 3.



[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 115.

$3\frac{3}{4}$ inches, and the thickness of the metal is between 2 inches and $\frac{3}{4}$ inch. In most cases the bolts are between 6 inches and 9 inches apart, and 1 inch diameter for the smaller tunnels up to $1\frac{1}{2}$ inch diameter for the largest. In the St. Clair Tunnel, however, the bolts are $\frac{7}{8}$ inch in diameter, and are 4 inches to 5 inches apart. There are so many uncertain factors, especially as to the amount of pressure, and the resistances of different kinds of joints, that the strains in an iron ring cannot be determined in the same certain manner as for most other iron structures. Hence a comparison of the different sizes becomes interesting, and is afforded in the following Table. The examples selected weigh between $16\frac{1}{2}$ tons in the case of the heaviest, and a little over 1 ton in the case of the lightest ring. The length,

Tunnel.	Weight per Foot.	Weight per Ring.	Weight per Foot of Diameter.
	Tons.	Tons.	Ton.
Blackwall	6·60	16·50	0·24
"	4·70	11·75	0·17
St. Clair	4·16	6·25	0·19
Edinburgh	3·16	4·75	0·17
Hudson[1]	2·56	4·25	0·13
Glasgow Harbour	2·05	3·05	0·12
Mersey Water	1·37	2·05	0·13
Waterloo and City Railway	1·09	1·80	0·08
Glasgow District Subway	1·00	1·50	0·08
East River (Gas)	1·25	1·65	0·12
Clichy	0·63	1·05	0·07

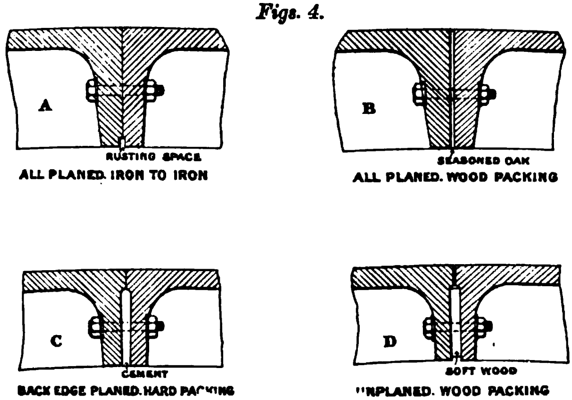
however, varies, the majority of the plates being 1 foot 6 inches or 1 foot 8 inches, measured in the direction of the length of the tunnel, and in the largest case 2 feet 6 inches. Much of the apparent difference disappears on reducing the weights to the amount for one lineal foot. Then the heaviest ring will be found to be 6·6 tons, and the lightest 0·63 ton. On comparing the relation between the weight and the diameter for tunnels similarly situated, the ratios very nearly agree throughout. The Author has visited all the iron tunnels in this country, and from a careful study of these, and of one or two examples in America, is of opinion that for tunnels passing under rivers or in soft yielding ground, or if close to heavy buildings, the weight of the iron shell per lineal foot in tons should be very nearly the outside diameter in feet multiplied by the inside diameter in feet divided by 100.

[1] Original section; weight afterwards increased by about one-third.

Thus at Blackwall 27 × 0·25 = 6·76; at St. Clair 21 × 0·1975 = 4·14; at Clichy 8·16 × 0·075 = 0·61, and so on. The thickness of metal should not be less than $\frac{3}{4}$ inch. Before applying this rule an appropriate depth of flange must be fixed, for it would be quite possible to make an abnormal ring having almost no flange and yet have the necessary weight. In no less than six cases the diameter in feet multiplied by 0·031 is equal to the depth of the flange in feet, and for the cases under consideration, in unfavourable circumstances, 0·038 would be about the ratio to take. In the case of tunnels which pass through fairly good ground, 0·031 for the depth of flange and three-quarters of the weight already given would be sufficient.

The disposition of the metal in the horizontal joints of the ring

Figs. 4.



TYPES OF JOINTS.

is the most important consideration of all, for without an efficient joint the above ratios and weights would be of no use. The thickness of the flange should slightly exceed that of the body of the plate, and be tapered from the back to the front of the flange. Without flanges, the ring would yield to the least pressure, and consequently, if the flanges do not give a firm connection between the segments, the ring will still yield, and the firmer the connection the stronger will be the ring. Two classes of flange have been used, the flat-faced, bearing equally from the front to the back, and the flange with a projecting fillet at the back, the intervening space being filled with cement or soft wood. The four joints are shown in *Figs. 4*. The objects to be attained are strength, watertightness, and cheapness.

The most trying conditions under which an iron ring can

be placed occur when the tunnel passes through ground which is not self-sustaining, or semi-fluid. Then, in addition to the pressure caused by any irregular yielding of the soft material, a considerable unequal pressure is caused by the weight of the tunnel being very much smaller than the weight of the displaced material. This ratio has been as much as one to four, and the lighter the tunnel, and the more buoyant it is, the greater is the unequal pressure upon it. It is very difficult to exactly determine this pressure, but from observations at Glasgow, and from the accounts of other tunnels, especially at the Hudson, where the temporary shell used in the original method of construction was too weak, and thus afforded a large practical experiment, the Author is convinced that it does exist, and that the peculiarities of semi-fluid materials do cause unequal pressures on the ring. To attain the first object, strength, it is therefore necessary to have a strong joint, bearing equally over the whole depth of the flange. Undoubtedly the joint A is the best, and B the next. Perfect rigidity is not desirable, but even with the joint A the ring is sufficiently yielding to be safe. Joints of the class C and D are not suitable for the horizontal position. In them, the fillets at the back either touch, or they do not touch. If they do not, then the joint does not bear at the back, where it should if anywhere, and a great part of the effective depth of the flange is lost. If they do touch, they remain in contact while the wooden packing is compressed; the flanges approach each other at the inside point, are then no longer parallel, and the ring must lose its circular shape. The point of greatest pressure is then transferred to the inside of the flange, and the fillets separate again. It becomes necessary, if this joint is used in plastic ground, to insert wedges to keep the flanges from coming together, but in any case the pressure is not evenly distributed, and much is put on the point of the flanges, which is very objectionable. Indeed, the Author had seen a flange broken near the bolt-hole simply by driving in a wedge. To obtain the second object, watertightness, joint A is again the best, a small check at the front for rusting keeping it quite dry. It is necessary to caulk a wooden packing, which, though effective, is not so permanent, and can never be, so long as it contains an element liable to decay. With the improved machinery now existing, the cost of planing differs so little from the cost of packing and caulking that with its other advantages it is really the cheapest; undoubtedly it makes the most effective horizontal joint; 75 per cent. of the iron tunnels have flat joints, or are made almost equal with cement packing. To

gain the curvature on the tunnel, the vertical joint may be wood-packed, but these joints do not play the same part in the stability of the tube. In straight tunnels, with all the flanges planed, should any eccentricity of the shield cause it to deviate from the true line, a lead packing is used to correct it. The top plates have the flange next the crown not radial but vertical, to facilitate fitting the key-piece, or the key may be made slightly wedge-shaped.

It has been said that the iron ring is not meant to stand up in the open air, but only when supported by the ground at the side acting as abutments. The Author, however, considers that the test is a very good one, especially for a ring to be used in soft yielding ground, where the abutment cannot be relied on. It shows at once the advantage of planed joints, which will stand up when wood-packed joints yield considerably. A large ring even with planed joints yields an inch or two. An interesting experiment on an 11-foot ring, with all the joints faced, showed that it did not deflect at all on being erected in the open air, and that a pressure of 7 tons on a vertical tie was required to deflect it half an inch. A similar ring of a little larger diameter, with soft-wood joints, yielded 2 inches by its own weight, and could be extended to 6 inches. The latter was suitable for self-sustaining ground, and the former for any ground, such as where grouting in the ordinary sense was not feasible.

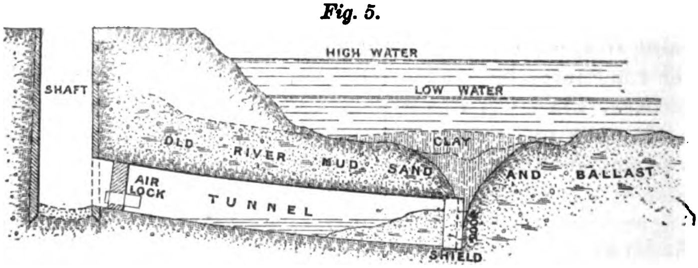
Effects of Air-Pressure.

Artificial air-pressure being an expedient only used during the construction of the works, none of the effects of air-pressure have any bearing upon their stability. The air-pressure is merely an aid to get out the excavation; the chief object being to keep out any water that would interfere with that operation. Sometimes this rule is not followed. First, in very soft ground, if it is thought necessary to adopt grouting. In that case the air-pressure must be increased, for grout injected in the ordinary way does not flow round the tunnel in the same manner as when the material is self-sustaining. It mixes with the soft material, and often blows straight into it opposite the grout-hole. To insert grout, therefore, a timber tunnel must be built in advance of the iron tunnel; and to do this more pressure is needed to aid in creating and preserving space between the two till the grout casing is inserted. This, however, is an operation which does away with the advantages of the independent shield, and, in any case, can only be carried out at great cost. The insertion of grout does not remove any

unequal pressure; unless it is made so thick as to act as a hoop round the tunnel it is useless, and, as the grout cannot be relied on as a sustaining part of the tunnel in soft ground which will close in round the tunnel itself, grouting is not used in the sense of a coating but is only forced in where possible, and is, in fact, sometimes omitted. At the Hudson Tunnel, where the silt was always found to be pressing close against the ring, the plates were made without a grout-hole. The soft material presses so eagerly into the tunnel by the grout-hole that the Author has known it almost overpower the grouter. In such cases, grouting is worse than useless, for the soft ground will still yield to unequal pressure whether the grout is inserted or not, and the iron ring will yield, too, if not strong enough, and is sure to do so if the joints are not firm.

Secondly, the air-pressure must be reduced below that which would balance the water-pressure if its escape does any damage.

Fig. 5.



This is the chief difficulty in applying compressed air horizontally. The head of pressure at the bottom of the tunnel being in excess of that at the top, the latter pressure will be overpowered and an escape of air will take place. In ballast, or any other gravelly and open material, the air will blow out, carry away the minute particles, and any small underground accumulations of water, not only honey-combing the ground in front but wasting power. So much so is this the case that the ground ahead is frequently grouted to minimise the escape. The lighter the cover the more will the air blow off. In passing under rivers, the effect of the escaping air on the material composing the river-bed determines the pressure that must be used. It cannot be assumed that in all circumstances the tunnel can be kept clear of water, nor does this matter, except as regards the time required for doing the work.

In *Fig. 5* is shown a tunnel being driven under a river. Its

diameter being taken at 20 feet, the cover at 15 feet, and the depth of the river at low water 15 feet, then the air-pressure required to dry the bottom of the tunnel will be about 10 lbs. per square inch in excess of that required to overcome the pressure at the top of the tunnel. The air will then escape; and, in material which possesses little or no tenacity, will gradually work up to the bottom of the river. The ground above the front of the shield becomes honey-combed and broken by the continuous working of the escaping air, and if the action is maintained, a point will soon be reached when the upward pressure will exceed the downward pressure and the cover will be blown away. The water then pours in, carrying with it much of the surrounding material. Hence the advantage of the shield with the front compartments. Very often a threatened blow can be confined to one compartment, or, at the worst, the front of the shield only is blocked with the material which has been washed in, the tunnel itself being merely flooded. With an assisted shield with a front diaphragm and large central door to facilitate working in front, the material washed in by the sudden inflow of water runs into the tunnel and fills it till the diaphragm door is blocked, when a water seal is formed and the agitation dies out. Matters are then in the position shown in *Fig. 5.* A blow out is not at all a rare occurrence, and usually happens to a greater or less extent wherever the balance between the upward and downward pressures is unequal. The Author was engaged at a tunnel driven through sand during one of these outbreaks, and on inspecting the place afterwards he observed that pieces of coal and sticks, &c., and even a door-mat had come down from the river bottom, 13 feet above, which had been destroyed by a pressure of between 19 lbs. and 20 lbs. A very peculiar instance is given by Mr. Aims in his Paper,[1] of similar debris coming down through more than 40 feet of cover through the openings made by the escaping air. To resume operations, the hole must be filled, preferably with clay, when the pressure of air can be raised again and the work continued. With this experience as a guide, precautionary measures may be taken beforehand, by spreading a regular and even coat of clay in the river-bed, and by timely relaxing the air-pressure. These measures aid in preserving the natural bed of the river. It is interesting to note that Trevithick used clay in this way in 1807 on the bed of the Thames.[2]

---

[1] See footnote, p. 380.

[2] "Life of Richard Trevithick," by Francis Trevithick. London, 1872, vol. i. p. 264.

As peculiar instances of the effects of air-pressure, the Mersey and Hudson tunnels may be mentioned. At the first named the difficulty of using horizontal air-pressure was aggravated by the fact that the ground passed through was very variable. Even though it is bad, if the material is the same all round, the probable results may be foreseen. At the Mersey, however, several kinds of strata, all loose material, and all requiring different pressures of air to keep them dry, were frequently met at the same time. The difficulties were still further increased by encountering huge trunks of trees buried in the river-bed. The air-pressure used was between 15 lbs. and 18 lbs. per square inch; the cover was 30 feet of gravel and sand, and 20 feet of water above at high tide. At low tide, 14 feet lower, the pressure could only be reduced 2 lbs. In these circumstances it could not be expected that the air would never blow out; and by employing an independent shield and trap partition behind, and allowing the ground time to settle down after each disturbance, the work after being fairly started was very soon accomplished.

At the Hudson Tunnel, the pressure required in the original method to dry the bottom was 9 lbs. per square inch more than that required for the top, and the silt was of such a nature that when dry it fell down in large lumps, and when too wet it began to close in on the working face. On one occasion, when working with an intermediate lock, the escape of air was so great that the pressure was sufficiently reduced to cause both doors of this lock to stand open. The silt at the face, closing in rapidly owing to the reduction of pressure, plugged up the escape, and the pressure rose again and closed the lock door as it was at first. The cover of silt was 20 feet and the depth of water above 50 feet; between the locks and at the face the pressures were 15 lbs. and 33 lbs. per square inch respectively. Afterwards, when the shield was introduced, it was simply driven ahead, and the material squeezed through the openings in the diaphragm.

In contrast to the difficulties at these works, and showing the very important results of having good cover, the St. Clair Tunnel may be quoted. Here the material passed through was soft and very wet blue clay. The least cover of clay was 8 feet, above which was 1 foot or 2 feet of sand and rubbish in the river-bed. The clay being a tenacious material, air-pressure was used under the river up to 28 lbs. per square inch, and no trouble resulted from escape. Had the cover been all sand and rubbish that pressure would have blown it away. The progress was exceedingly good; two shields started 6,000 feet apart, and the headings

met in one year. In three consecutive months one shield excavated 1,092 feet length of tunnel.

The pressure theoretically necessary to balance a water column is 0·43 lb. per square inch per foot of depth. In practice it varies considerably, being usually less, owing to the ground not readily admitting water to pass through it, and is sometimes only three-quarters of the calculated pressure. If, however, the water being once in, it is required to dry the surrounding ground by forcing the water out of it, the pressure is increased; but this is very different from only preventing the water from flowing into the tunnel. The highest pressure used was 52 lbs. per square inch at the East River Tunnel, where the depth from the top of the water was 120 feet.

The advantage of using electric light is very great, as far as keeping a pure atmosphere is concerned. In compressed air candles make an excessive smoke, and if there is no escape at the face a thick atmosphere is caused, which is more harmful than a higher pressure with pure air. Even with clean air, 35 lbs. per square inch is the highest pressure for large practical operations.

The number of iron tunnels hitherto built is not large, and the circumstances are so varied that no definite rule as to cost can be laid down. Generally it may be said that taking the cast-iron alone at customary rates, 30*s.* per cubic yard will be fairly moderate. Without too many difficulties, 40*s.* to 45*s.*, and in the worst case of passing under a bad river 80*s.* per cubic yard will be about the cost of excavation. Fifteen feet of tunnel per day have been accomplished in favourable circumstances. An average of 10 feet is good progress; with even moderate difficulties an average of 5 feet or 6 feet per day; and in the most disadvantageous circumstances a speed of 3 feet per day may be relied on.

The life of an iron tunnel should not be any less than that of a brick one. It will be interesting to watch the effect of locomotive gases on the plates. At St. Clair an electric locomotive is employed in the tunnel, but at Edinburgh ordinary engines are used. The tunnels there are so short, however, that they soon clear of steam, &c. A protective lining could easily be inserted. This has already been the case at several places, either to deaden the sound of passing trains, or to give the tunnel a more finished appearance.

For cross-river communication the Glasgow Harbour Tunnel affords a very good example. There are three 17-foot tubes, two for vehicular traffic, and one in the centre for pedestrians. This tunnel is steeply inclined at the ends, and lands the passengers almost at the quay-level. The vehicles are raised and lowered to the outer

tunnels, which are level, by six large hydraulic-lifts, each taking $5\frac{1}{2}$ tons. The excavation is only about one-fifth more, the available floor-space is double, the weight of iron is the same, and the shafts are not so deep as for a single 27-foot tunnel. The City and South London Railway has demonstrated the great practical utility of the iron tunnel system. The Blackwall Tunnel, the driving of which through watery ballast at places only about the height of a man below the original river-bed, is perhaps one of the most difficult works. The work has not yet been completed, but its success is assured, for the under-river portion is finished, and in October last it was the scene of a great festive gathering, recalling the similar entertainments given by Brunel in the Thames Tunnel, but also showing in the most striking manner, after the lapse of half a century, the perfection to which the method he originated has attained.[1]

The Author was engaged for a time on part of the works of the Glasgow District Subway, and has visited all the iron tunnels in this country, and part of the Hudson works before the original method was abandoned. He is much indebted to the many engineers and contractors who were good enough to allow him to refer to their works, and whose kind permission enabled this communication to be written.

The Paper is accompanied by seven drawings, from which the *Figs.* in the text have been prepared, and by a set of photographs showing interior views of several of the tunnels referred to.

[1] Lecture by A. R. Binnie, M. Inst. C.E., before the Royal Institution, 6 March, 1896.

OBITUARY.

PHILIP BARRY, M.E., born in 1832, was educated at Queen's College, Cork. In 1859 he obtained the engineering diploma of the Queen's University, Dublin, at which he took the degree of B.E. in 1871. On the dissolution of the University in 1882 the degree of M.E., *honoris causa*, was conferred upon him.

Mr. Barry gained his first practical experience in 1858–59 on the construction of the Mallow and Fermoy Railway, and from 1860 to 1866 he was employed as resident engineer, for the late Mr. J. P. Ronayne,[1] on the construction of the Queenstown and the Cork and Macroom lines. He then practised on his own account in Cork for seven years, during part of which time he carried out important works for the Gas Consumers' Company of that city. In May, 1873, he was appointed engineer to the Cork Harbour Commissioners, which post he held for upwards of twenty-two years. At the date of his appointment there was urgent necessity for better accommodation for vessels, the depth at the old quays being only 7 feet at low water. To meet this necessity with the least possible delay a timber wharf was constructed in front of the Victoria Quay, 1024 feet in length, projecting 20 feet outside the quay wall. This projection enabled the river to be dredged without endangering the quay, so as to afford a depth of 19 feet at low water for vessels lying at the wharf. Mr. Barry contributed to the Institution in 1890 an account of this work, of the deep-water quays which were subsequently constructed, and of other improvements to the port carried out under his charge.[2]

Mr. Barry died at his residence, Rosetta, Blackrock, Cork, on the 11th November, 1895. He was elected an Associate on the 6th April, 1875, and was transferred to the class of Member on the 15th January, 1878.

GEORGE BOND, born on the 9th December, 1840, was the son of Mr. G. H. Bond, mining engineer, of Nottingham. After being educated at Heidelberg he became a naval cadet. He abandoned

[1] Minutes of Proceedings Inst. C.E., vol. xlvi. p. 274.
[2] *Ibid*, vol. c. p. 315.

the sea, however, and from 1859 served an apprenticeship to his father. On the breaking out of the American Civil War in 1862 his roving disposition re-asserted itself, and he was engaged in several ventures of blockade-running at New Orleans. He then became manager of the Mostyn Hall Colliery, and in 1867 sub-manager, under his father, of the South Wales Mineral Railway. He was also occupied at this period on the erection of blast-furnaces in Northamptonshire.

Mr. Bond's connection with the Staveley Coal and Iron Company commenced in 1872. On the death of Mr. Charles Markham [1] in 1888 he was appointed general manager and engineer of the Company's extensive works and collieries. During the period of his management several large coal-fields were acquired, among them one at Warsop and another at Temple Normanton, at the latter of which a pit was sunk called Bond's Main Colliery. He was also responsible for the laying out and construction of railways in connection with the ironstone mines belonging to the Company.

Mr. Bond died suddenly at Tapton House, Chesterfield, the residence of Mrs. Markham, on the 22nd of April, 1896. As a man he was genial and generous, and to his determination and energy was due a long fight against the heart affection which finally caused his death. He was a Justice of the Peace for Derbyshire and Chairman of the Brimington Parish Council. Mr. Bond was elected a Member on the 7th May, 1889.

HUMPHREY CHAMBERLAIN, born on the 26th May, 1846, was the son of the late Mr. Humphrey Chamberlain, who was then manager of pottery works at Worcester and subsequently agent for many years to Messrs. Bradley and Craven, of Wakefield. After being educated at Worcester Collegiate School and in Germany, the subject of this notice was apprenticed in 1863 to Messrs. Bradley and Craven, and in the following year was sent by that firm to Buenos Ayres to superintend the erection of some machinery. From June, 1866, to January, 1867, he acted as an Assistant Engineer on the preliminary surveys of the Central Uruguay Railway. He was then engaged for ten months on the contractor's staff of the Midland Railway extension from Bedford to St. Pancras, and was subsequently for a time again in the employment of Messrs. Bradley and Craven.

---

[1] Minutes of Proceedings Inst. C.E., vol. xcv. p. 377.

In October, 1868, Mr. Chamberlain was appointed Locomotive Superintendent of the Central Uruguay Railway, in the service of which Company he spent the remainder of his life. In July, 1873, he became Chief Resident Engineer of the line, and in addition to the duties of that post he acted since 1878 as General Manager. The climate of South America, however, severely affected his health and in 1891 he was obliged to take sick leave. On returning in the following year he was again prostrated by heart disease and liver complaint, and in 1895 he was obliged to come home once more. He died at Upper Norwood on the 9th January, 1896. Mr. Chamberlain was much liked and respected, both at home and abroad. Shortly before his death he was "decreed" Consulting Engineer in England for the republic of Uruguay. He was elected an Associate on the 29th May, 1877, was subsequently placed among the Associate Members, and on the 14th May, 1889, was transferred to the class of Member.

JABEZ CHURCH, born at Chelmsford in 1845, was the son and grandson of well-known engineers bearing the same name. After being privately educated he was articled to his father,[1] who had gained considerable reputation as a gas and water engineer. In 1867 he became a Student of the Institution, being one of the first candidates admitted into that class. Two years later he was taken into partnership by his father, and on the death of the latter in 1875 he continued the practice alone.

Among the works which Mr. Church designed and constructed, or for which he was professionally engaged, may be mentioned the gasworks at Braintree, Barking, Brentwood, Enfield, Epping, Harwich, Ilford, Saffron Walden, Woking, Horley, Thetford, Barnet, Colney Hatch, Cromer; also the Dublin Consumers' Gas Company's works; and the waterworks at Barnet, Henley-on-Thames, Great Marlow, Godalming, Clacton-on-Sea, Barton-on-Humber, Goring, the Mid-Sussex works, and the Witham water and drainage undertakings. Mr. Church also designed and carried out extensions of the works for the water-supply of Braintree and of Halstead, and those now in course of construction at Gainsborough were likewise designed by him.

Mr. Church died at his residence, 17 Holland Park Gardens, Kensington, on the 20th of March, 1896, death being due to con-

[1] Minutes of Proceedings Inst. C.E., vol. xli. p. 211.

gestion of the lungs and heart disease. He was a Fellow of the Geological Society and of the Royal Meteorological Society, and was for two years in succession (1882 and 1883) President of the Society of Engineers. Upright and honourable in all his dealings, he was deservedly esteemed both professionally and privately. Mr. Church was elected an Associate on the 23rd of May, 1871, and was transferred to the class of Member on the 27th of November, 1877.

WILLIAM JOHN BIRD CLERKE, B.A., C.I.E., was born on the 3rd of February, 1838, at Lorigga, near Skibbereen, co. Cork. He was educated at Dr. Stackpoole's school, Kingstown, and obtained a mathematical sizarship at Trinity College, Dublin, where he gained the engineering diploma and graduated B.A. in 1860. In the same year he became a pupil of the late Mr. W. R. Le Fanu,[1] well known as a railway engineer in Ireland. He was then employed for five years on the construction of the Dublin, Wicklow and Wexford Railway, and subsequently on that of the Great Northern and Western of Ireland Railway for two years and a half.

The greater part of Mr. Clerke's professional life was, however, spent in the service of the Public Works Department of the Government of India, which he entered in December, 1868. On arrival in Bombay he was sent into the Rajputana district to aid in famine relief operations there, and was subsequently employed in maturing the Taptee Irrigation scheme, which work he actually commenced. During the great famine of 1876-77 in the Bombay Presidency employment had to be found for large masses of unskilled and inexperienced workmen, and it was due in a great measure to Mr. Clerke's powers of organization that under such conditions many large irrigation works of permanent utility were designed and constructed in the Poona district. Among these may be mentioned the tanks at Supa, Matoba, Sirsophal, Patus and Bhadalwadi, and the Mutha Canal extension.

In 1883 Mr. Clerke was in England on leave. On his return in the following year his services were placed at the disposal of the Municipality of Bombay which had applied to the government for an officer to revise and report on Major Tulloch's Tansa project for the additional water-supply of the city. In August, 1885, he

[1] Minutes of Proceedings Inst. C.E., vol. cxix. p. 395.

submitted a report, with general plans and estimates, and in the following January the construction of the masonry dam at Tansa was commenced under his charge. The works, which were opened on the 31st of March, 1892, by the Marquis of Lansdowne, Viceroy of India, were described by Mr. Clerke in a Paper read at the Institution in the following year.[1] In recognition of his share in this vast undertaking, Mr. Clerke was created a Companion of the Order of the Indian Empire, while the Council of the Institution awarded him a Telford medal and premium for his Paper.

Mr. Clerke then returned to this country, leaving behind him a singularly high official reputation. In January, 1894, he was appointed an engineering inspector under the Local Government Board, and to the performance of the duties of this post he devoted the same conscientiousness and energy which had made him successful in India. But his career was unfortunately brought early to a close. He was attacked by a malignant disease of the throat and was called upon to decide between the risk of a lingering and painful death, or a dangerous operation with some chance of recovery. He chose the latter and faced the operation with a courage which won the admiration both of his friends and of the surgeons in attendance. Although it appeared successful, pneumonia supervened, and he died on the 13th of February, 1896, within forty-eight hours of the operation.

Mr. Clerke's ability as an engineer has been fully indicated by the foregoing notice. He had decided views and was not easily induced to alter his convictions, although he always sought to express them in such a way as not to wound others. His industry and capacity, coupled with entire fairness, were in a great measure the cause of his success in undertakings when many subordinates had to be dealt with by the force of example. His genial and unselfish nature won friends for him wherever he went. Mr. Clerke was elected a Member on the 2nd of May, 1871, and during his residence in London frequently attended the meetings of the Institution.

WILLIAM CRABTREE, born at Hebden Bridge, Yorkshire, on the 10th of January, 1826, was the youngest son of Mr. Richard Crabtree, a contractor of some repute in that part of the Calder Valley.

After being educated at a private school he entered the office

[1] Minutes of Proceedings Inst. C.E., vol. cxv. p. 12.

of his father in 1841, and gained considerable practical knowledge of stone-quarrying and in the construction of masonry bridges, reservoirs and other works. In 1847 he superintended the construction of a viaduct at Dewsbury for the London and North Western Railway. In 1848, on the death of his father, he entered into partnership with his brother, the late Mr. Lewis Crabtree, as contractor for earthworks, masonry, and gas- and waterworks. They had quarries at Wadsworth, Stansfield, and Heptonstall, and constructed Heptonstall Church, Hebden Bridge Gas Works, fourteen mills or factories in the neighbourhood, and the massive monument erected on Studley Pike to commemorate the declaration of peace on the conclusion of the war with Russia.

Mr. William Crabtree being desirous of extending his experience, left his native village, where his brothers still carried on the business of contractors, and from 1854–57 was engaged on the East Lancashire Railway, under Mr. J. S. Perring,[1] in superintending the erection of the locomotive works at Bury and on the extension from Burscough into Southport. On the amalgamation of the East Lancashire with the Lancashire and Yorkshire Railway Company, Mr. Crabtree entered the office of Mr. Edward Salomon, an architect with an extensive practice in Manchester, and from 1857–59 he superintended the erection of the Manchester Art Treasures Exhibition and several large warehouses and buildings of a similar character. In 1860, on the recommendation of Mr. Salomon, he became engineer to the firm of Messrs. J. and T. B. Crompton, paper makers, for whom he constructed several reservoirs and filter beds, and arched over the River Douglas which ran through the mills. He also superintended the erection of new engines and machinery of the most approved type for making various kinds of paper.

In 1867, Mr. Crabtree was appointed surveyor to the borough of Southport, which had just been incorporated. One of his first duties was to investigate and report upon the difficult problem of sewerage and sewage disposal for a widespread and rapidly growing community, situated in an absolutely level country. He examined and reported upon every known system, both in England and on the Continent; and finally he advised alternative schemes, one of which was adopted on the recommendation of Messrs. Lawson and Mansergh, and subsequently, Mr. Lawson having died in the interim, the works were designed and carried out by Mr. Man-

[1] Minutes of Proceedings Inst. C.E., vol. xxx. p. 455.

sergh at a cost of £120,000. Notwithstanding great difficulties, both in the nature of the ground and the levels of the country, the works were successfully carried out in the years 1875 and 1876. Mr. Crabtree subsequently constructed about 30 miles of main sewers. Between the years 1885 and 1890 the following works in Southport were executed from the designs and under the superintendence of Mr. Crabtree:—sea-walls, marine drives, promenades, lakes and bridges on the sea front; street-improvements, parks and pleasure grounds, sewerage extensions, bridges, and various public buildings.

Mr. Crabtree was a man of indomitable energy, for which he found scope at Southport during the twenty-nine years he held the office of Borough Surveyor. He was highly esteemed by those who knew him, and he received, on more than one occasion, tempting offers to leave the town of his adoption, but family ties and the pride and interest he took in his work at Southport kept him from moving elsewhere. He died at his residence, Zetland House, Southport, on the 21st of February, 1896, aged seventy, after a long illness, arising from an attack of influenza two years previously, followed by a series of complications.

He was elected an Associate on the 6th of April, 1875, and was transferred to the class of Member on the 1st of May, 1883. He was a Freemason of nearly fifty years' standing.

ALFRED FRASER, born in Southwark on the 5th of July, 1853, was the only son of the late Mr. Alexander Fraser,[1] for many years Engineer to the Grand Junction Waterworks Company, whose death took place only four months before that of the subject of this notice. Alfred was brought up from boyhood in the Engineering Department of the Grand Junction Waterworks and assisted his father in carrying out many important works for the Company. He superintended the construction of a large covered reservoir at Kilburn, and was engaged for some years in making plans of the whole of the Company's district, extending from Haymarket to Sunbury, with all the various pipes, hydrants and works therein. In 1893 he was appointed District Engineer, with charge of the outdoor staff, and became responsible for all facts and information relating to the supply of water to the whole district, containing a population of about 500,000.

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 433.

Mr. Fraser suffered many years from indifferent health, which prevented him from taking a prominent part in the more active duties of the profession. He died at The Mount, Ealing, from an attack of rheumatic fever, on the 6th of February, 1896. Mr. Fraser was a clever draughtsman, and, like his father, was retiring in disposition, but was much respected by those who knew him well. He was elected a Member on the 1st of May, 1894.

HARRY CORBYN LEVINGE, born on the 1st of December, 1828, was the youngest son of Sir Richard Levinge, sixth baronet, and of Elizabeth Anne, daughter of Lord Rancliffe. He was educated at Trinity College, Dublin, where he graduated B.A., and was then articled to Mr. S. U. Roberts, under whom he was engaged on the drainage works of Lough Corrib in Galway. In 1854 he entered the service of the East Indian Railway Company, and was employed on works under construction in the province of Bengal until 1862, when he was appointed to the staff of the East India Irrigation and Canal Company. This Company was then about to carry out an extensive scheme of irrigation in the Orissa Delta, on which Mr. Levinge was engaged for seven years, first as a District and afterwards as Chief Engineer, until the works were taken over by the Government of India, when he and most of the officers of the Company were transferred to the Public Works Department.

Mr. Levinge was then appointed Superintending Engineer of the important scheme of irrigation in the Delta of the Sone, which—after numerous surveys and the preparation of plans and estimates involving a great amount of labour—he successfully carried out. Some idea of the magnitude of these works may be formed from the fact that the great dam across the Sone is over 2½ miles long, is founded on sand alone, and is raised 9 feet above the summer level of the water. From the dam, on each bank of the river, are led off the main irrigating canals, which, with their branches, measure about 500 miles, nearly 400 miles being furnished with large locks. By means of these works communication was opened up throughout the Delta with the Ganges and thus with Calcutta.

In 1879 Mr. Levinge was appointed Chief Engineer and Secretary to the Bengal Government, which post he held until 1883, when he retired from the service, receiving a well-earned farewell order, couched in the highest terms, from the Governor of Bengal.

On the death of his brother, Sir Vere Levinge, eighth baronet, in 1885, he succeeded to the family property of Knock Drin Castle, co. Westmeath, and in the following year he was appointed High Sheriff of Westmeath. He subsequently served as Deputy Lieutenant of the county. Mr. Levinge had suffered for some time from an affection of the heart, from which he died, after a distressing illness, at Knock Drin Castle on the 11th of March, 1896. By his kind and genial disposition he gained many friends, while as a landlord he was just and considerate. He was elected a Member on the 5th of March, 1878.

DAVID LOGAN,[1] who was born on the 5th of June, 1832, came of an engineering family, his father having been for many years Engineer to the Clyde Navigation Trust. After serving an apprenticeship of five years to Mr. Thomas Kyle, an engineer and surveyor in large practice in Glasgow, the subject of this notice was engaged for two years on railway works under Mr. Charles Jopp, of Edinburgh, and then became an assistant to Messrs. Walker, Burges and Cooper, of Westminster.

On the recommendation of Mr. (now Sir George) Bruce, Mr. Logan was placed in 1858 on the staff of the Great Southern of India Railway. He was employed as resident on the Negapatam-Trichinopoly section until 1863, when he succeeded Mr. Mark W. Carr[2] as Chief Engineer of the line. Three years later he resigned that post in order to superintend the reclamation work at Back Bay, Bombay. In 1869 he was re-appointed Chief Engineer of the Great Southern of India Railway, which was at that time a 5-foot 6-inch gauge line, extending from Negapatam to Erode. Its subsequent development into the system now known as the South Indian Railway, about 1,100 miles in length, was carried out under Mr. Logan's direction.

Mr. Logan held this post until his death, from paralysis, which took place at Ammayanayakanur, a station on the South Indian Railway, on the 17th of April, 1896. His name will long be remembered as one of the earliest and most successful pioneers of railway enterprise in India. He was known as a reliable and economical engineer, but at the same time as one who never

---

[1] The substance of this notice has been taken from *Indian Engineering* 2 May, 1896.

[2] Minutes of Proceedings Inst. C.E., vol. xciii. p. 487.

allowed his instinct of economy to prejudice the safety and durability of the works under his control. To his great ability in reducing capital expenditure on construction is largely due the satisfactory financial condition of the South Indian Railway. In private life his genial disposition secured him many friends. Mr. Logan was elected a Member on the 3rd of December, 1867. In 1885 the distinction of Fellowship was conferred upon him by the University of Madras.

JAMES ADAIR McCONNOCHIE, who died at Brighton in his sixty-first year, on the 17th of December, 1895, after a long and painful illness, was born at Row on the Gareloch, Firth of Clyde, on the 21st of August, 1835, and afterwards resided at Glasgow, where he was educated at a private school. His father was for many years Superintendent of Works and Assistant Engineer on the Clyde Navigation. The subject of this notice was in 1849 apprenticed to Mr. Thomas Kyle, an engineer and surveyor in large practice in Glasgow, with whom he remained until 1854, when he was engaged as an assistant by Messrs. Walker, Burges and Cooper, of Westminster. In that capacity he assisted during the next eight years in the preparation of drawings of many important works, among them being in 1855 the contract drawings for the first portions of the Tyne Piers, the Dover Admiralty Pier, Plymouth Fort and Breakwater, and the Bishop Rock, Gunfleet, and other lighthouses erected for the Trinity House, to which Corporation Mr. Walker[1] was Chief Engineer. He also prepared drawings for extensive additions to the Commercial Docks (afterwards amalgamated with the Grand Surrey Docks and Canal Company, under the name of the Surrey Commercial Docks) and for other important works; and so well did he perform his duties, that at the time of the death of the junior partner, Mr. James Cooper,[2] in March, 1862, he was the Chief Assistant in the office. Mr. Walker died in the following October, and on the retirement of Mr. Burges the business of the firm was taken over by Messrs. McClean[3] and Stileman,[4] with whom Mr. McConnochie remained until March, 1865, when he was appointed Resident Engineer to the Surrey Commercial Dock Company.

---

[1] Minutes of Proceedings Inst. C.E., vol. xxii. p. 630.
[2] *Ibid*, vol. xxii. p. 624. [3] *Ibid*, vol. xxxviii. p. 287.
[4] *Ibid*, vol. xcviii. p. 401.

The following works for the alteration, extension or improvement of the Surrey Commercial Docks were executed from the designs and under the superintendence of Mr. McConnochie:—

In 1865 and 1866 the Lavender Dock, and the communication between the Stave Dock and the Lavender Pond; also a retaining wall about 1,550 feet long and puddle trench along the east side of Lavender Pond and Acorn Pond; from time to time the whole of the Albion Dock, Stave Dock, Russia Dock, and Norway Dock, which until 1866 had only sloping sides, were deepened and provided with timber quays throughout, the total length of which was about 3 miles. The Lady Dock was altered on two occasions, first a concrete quay wall was built on the west side, in substitution and in front of the sloping side. This wall was built without a dam by the placing of large concrete blocks by divers; whilst on the east side the concrete wall was constructed in a trench behind the slope and the dock was widened by the removal of the ground in front after the wall was completed. The Commercial Basin was constructed in 1866 and 1867. The Canada Dock, a new deep-water dock of 15½ acres, with communication passages to the Albion Dock and to the timber ponds, was constructed in 1875 and 1876. New sheds, covering 35 acres and costing about £160,000, and extensive grain warehouses, fitted with complete appliances (worked by hydraulic machinery), costing £150,000, were also designed by and executed under the superintendence of Mr. McConnochie, who likewise installed hydraulic machinery for working the principal gates, cranes and capstans, throughout the system.

In 1893 Mr. McConnochie, after reporting, prepared plans for an extensive addition to the dock accommodation of the Company. This consisted of a new deep entrance lock from the river, giving access to a new dock, 2,000 feet long and 400 feet wide, communicating by a 60-foot passage with the existing Canada Dock; also on the north side a new passage connecting the Russia Dock, and on the south side a new canal lock. For these works (estimated to cost £374,000) Parliamentary powers were obtained in 1894. He afterwards prepared the drawings and specifications for the first section of the work, the contract for which was let to Messrs. Pearson and Son, who commenced operations in April, 1895. Mr. McConnochie was also engaged on many other works on the River Thames and elsewhere. Among these were the Aberdeen Wharf, constructed in 1876, on a foundation formed of concrete cylinders, at a cost of £33,000, and the Christchurch Graving Dock at Cubitt Town. From 1882 until his death he acted as the London agent

of the Bombay Port Trustees, whose appreciation is adequately expressed in the following extract from a resolution passed by the Board on the receipt of the telegraphic news of his death:—"His services were of the highest value to the Trustees in all their transactions with home, including the purchase, inspection and approval of extensive dredging plant, and hydraulic and other machinery." Mr. McConnochie designed and carried out the Junction Graving Dock and Bute Graving Docks at Cardiff. He was also consulted in 1870 as to the construction of the dock gates and caisson of the Bute Docks, Cardiff, and more recently as to the plans for the extension of those docks, for which an Act was obtained in 1894. In 1890 he was engaged by Miss Talbot, and afterwards by the Port Talbot Railway and Docks Company, as Engineer. He recommended various improvements at the Port Talbot Docks, and in 1893 designed a comprehensive scheme for the enlargement and improvement of the harbour and docks, for which an Act was obtained in the following year. The parliamentary plans, contract drawings and specifications were prepared by Mr. McConnochie in conjunction with Mr. P. W. Meik, and the contract was let to Messrs. Pearson and Son, Mr. McConnochie up to the time of his death continuing to be joint engineer with Mr. Meik and Mr. T. Forster Brown. He also advised the Corporation of Bristol as to dock extension and other matters in 1893.

Mr. McConnochie was animated by a deep sense of duty not only to his employers but to all who served under him. Inflexible in purpose, he yet contrived to carry out his work with due consideration to the claims of others, while his manner was as gentle as it was firm. The following extract from a letter to Mrs. McConnochie from the Secretary of the Surrey Commercial Dock Company, dated the 19th of December, 1895, may well be quoted:—

"The sad intelligence was received by the Board with extreme regret, and I was desired to express to you the very great esteem which the Directors have always entertained for Mr. McConnochie personally, the high value they placed on the services he had rendered to the Company, and their sense of the loss sustained by his death, and to convey to you their sincere condolence and deep sympathy with you in this most trying bereavement."

Mr. McConnochie was married in July, 1876, to Jessie Forsyth, eldest daughter of the late Rev. Stephen Balmer, minister of the parish of Portpatrick, N.B. He was elected a Member on the 10th of January, 1865.

PETER JOHN MARGARY, who was born on the 2nd of June, 1820, in Kensington, commenced his engineering career in 1838, when he was articled to Mr. William Gravatt[1] who at that time was Isambard K. Brunel's[2] chief assistant on the Bristol and Exeter Railway, the works of which had just been commenced. After the expiration of his articles Mr. Margary was appointed an assistant to Mr. William Froude[3] who had succeeded Mr. Gravatt and had charge of the works of the eastern portion of the Bristol and Exeter Railway. On the commencement of the South Devon Railway Mr. Margary was given the charge of a portion of these works and assisted Mr. Brunel in carrying out on that railway the atmospheric system of traction, which, however, was only used for a brief period on the section between Exeter and Newton Abbot. Many engineering difficulties were encountered in the construction of the South Devon Railway, which is carried in many places under the cliffs and close to the coast-line, constant breaches and damage being caused by the inroads of the sea. These were successfully overcome, and it is interesting to note that in a report made in 1853 by Mr. Brunel to the Directors of the South Devon Railway upon a serious breach and slip which had occurred at a point on the line a short distance west of Dawlish, he said:—

"I cannot conclude my report on this occasion without referring to the skill and untiring energy displayed by your resident engineer, Mr. Margary, to whose prompt and judicious executions under emergencies involving considerable difficulties the Company and the public are indebted for a great reduction of the inconvenience caused by the accidents which have occurred. In the case of the slip at Breeches Rock particularly, a temporary wall was most skilfully and rapidly constructed, while exposed to the violence of the seas, in a manner which will serve as a most useful example in sea-works."

Upon the decease of Mr. Brunel in 1859, Mr. Margary was appointed Chief Engineer of the South Devon Railway. He subsequently carried through Parliament the scheme for the extension of the Tavistock Railway to Launceston which was strenuously opposed, and also the branches to Moreton-Hampstead, Ashburton, and St. Ives in Cornwall. The whole of these lines he designed and successfully completed, though they involved works of great difficulty, requiring skill, ability and energy to overcome.

In 1868 Mr. Margary was appointed Chief Engineer to the Cornwall Railway Company, in addition to his duties on the South

---

[1] Minutes of Proceedings Inst. C.E., vol. xxvi. p. 565.
[2] *Ibid*, vol. xix. p. 169. [3] *Ibid*, vol. lx. p. 395.

Devon Railway, and its various branches. These appointments he continued to hold until the amalgamation of those lines with the Great Western Railway in the year 1876, when he was appointed Resident Engineer of the Western Division of that Company's system. That post included the charge of the Great Western Docks at Plymouth, where between 1878 and 1881 he carried out the construction of the West Wharf, the deepening of the entrance channel and the extension of the graving dock. He also at that time reconstructed the St. Pinnock and Moorswater Viaducts on the Cornwall Railway, a description of which he presented to the Institution.[1] Towards the latter end of 1891 Mr. Margary retired on a well-earned pension. His retirement was taken advantage of by upwards of 500 of his colleagues and assistants, to present him with a testimonial of their appreciation of his ability, and the respect and kindly feeling which they felt for him. This address was enclosed in a silver casket and was presented in the presence of a great number of his brother officials.

Mr. Margary did not long enjoy his well-earned repose, for he died in London of heart disease on the 29th of April, 1896. His death causes another breach in the ranks of those engineers who were brought up amongst the early surroundings of the great railway developments of fifty years ago. He was a man whose life was spent in assisting in no small measure in those developments, and his strong force of character and strict sense of duty, as well as his upright and conscientious conduct on all occasions, will long be remembered by those who were associated with him. He was elected an Associate on the 2nd of March, 1847, and was transferred to the class of Member on the 31st of January, 1860.

THOMAS MEIK, who was born on the 20th of January, 1812, at Duddingston, near Edinburgh, came of an old Perthshire family, at one time the owners of considerable property in the neighbourhood of Coupar Angus. He was educated at the High School and at the University of Edinburgh, from which he went for two years to a firm of millwrights named Moodie, and was then apprenticed for a similar period to Mr. John Steedman, engineer and contractor, at that time engaged in building the Hutcheson Bridge, Glasgow. On the conclusion of his apprenticeship he obtained,

[1] Minutes of Proceedings Inst. C.E., vol. lxix. p. 312.

through the influence of Colonel (subsequently General Sir) Charles Pasley, K.C.B., R.E.,[1] an appointment on the ordnance survey of Ireland, which, however, he did not retain long, as in 1833 he accepted the post of assistant to Mr. W. C. Mylne,[2] engineer to the New River Company. He remained on the New River works until 1845, during the first few years in Mr. Mylne's office and subsequently employed on out-door work, being appointed chief Assistant-Engineer to the Company under Mr. Mylne. During that period Mr. Meik was engaged in a variety of general work in addition to that of the New River Company, including the water-supply of Hastings and Stamford, bridges at Cambridge and elsewhere, and the survey of a railway from London to Brighton. After his appointment as Assistant-Engineer to the Company, he lived on the New River at Bush Hill near Enfield, and had special charge of the sinking of two wells, one of which was at Cheshunt.

In 1845 Mr. Meik was appointed Engineer to the River Wear Commission in succession to Mr. John Murray,[3] who had become Engineer to the Sunderland Dock Company formed under the chairmanship of George Hudson, the "Railway King," to construct a large dock on the south side of the Wear. The dock undertaking was purchased by the Commission in 1859 and from that time Mr. Meik had charge of the whole work of the port. During his residence at Sunderland the works carried out by the Commissioners were very extensive, including large dredging operations in the river, the construction of the Hendon Dock, with a separate entrance to the sea, and the enlargement of the Southern outlet from the dock by the construction of the New South-west Breakwater and other works. Mr. Meik's duties also included the design and construction of a graving dock, grain warehouses, quays, fixed and swing bridges, coal staiths and the other usual adjuncts of a large harbour and dock undertaking. A great deal of the work of the Commission was executed by its own staff without the assistance of a contractor, and as the New Hendon Dock works were constructed in this way the duties of the engineer were very onerous.

These important works were finished in 1867, and in 1868 Mr. Meik resigned his appointment as Engineer to the River Wear Commission, and was succeeded by Mr. H. H. Wake, a former pupil, Mr. Meik being retained as Consulting Engineer. He then

---

[1] Minutes of Proceedings Inst. C.E., vol. xxi. p. 545.
[2] *Ibid*, vol. xxx. p. 448. [3] *Ibid*, vol. lxxi. p. 400.

took into partnership another old pupil and assistant, Mr. W. D. Nisbet, and commenced business both in Sunderland and Edinburgh, Mr. Meik going to reside in Edinburgh, while Mr. Nisbet remained in Sunderland. The firm carried out extensive works in the North of England and in Scotland, including new wet docks at Burntisland and Ayr, harbour works at Blyth and Warkworth, the water-supply of Bedlington, foreshore protection works at Bridlington, a graving dock and quays on the Wear, and the Hylton, Southwick and Monkwearmouth Railway, afterwards taken over by the North Eastern Company.

In 1875 Mr. Nisbet left the firm to accept the post of Harbour Engineer to the Government of Queensland, and Mr. Meik then took into partnership his son, Patrick Walter, and a few years later another son, Charles Scott. The firm, reconstituted as Thomas Meik and Sons, executed further important works, including the dock and harbour at Bo'ness, the harbour of Eyemouth and the Eyemouth Branch Railway, and acted as consulting engineers for the new dock at Silloth. In 1876, Mr. Meik severed his connection with the River Wear Commission and in 1888 he retired from business.

In addition to the works referred to, Mr. Meik was consulted at various times by nearly every harbour authority in the north. He acted as Engineer to the Peterhead Harbour Trustees for their Act of 1876, and he designed the Port Henry Works at that place. He was twice asked to submit designs for docks at Stockton-on-Tees, and at Seaham and Arbroath. He gave evidence before the Royal Commission on Harbours of Refuge in 1859, before the Fishery Harbour Commission of 1884, and before many Parliamentary Committees on Harbour and Dock Bills.

Mr. Meik was a man of genial temperament and made many friends amongst his professional brethren, but in his later years he lived in quiet retirement. He had an excellent constitution and had hardly known what illness was till within a few months of his death. He passed away peacefully at his residence, 13 Newbattle Terrace, Edinburgh, at the mature age of eighty-four, on the 22nd of April, 1896, the fiftieth anniversary of his wedding-day. Mr. Meik was elected a Member on the 1st of May, 1866.

DAVID SIMMS, was born on the 5th of May, 1845. After being educated at a private school at Tottenham and at King's College, London, he was apprenticed in 1862 to Mr. James Abernethy, Past-President.[1] From May to October, 1864, he was engaged in Ireland as an Assistant-Engineer on the Banbridge Extension Railway, where he gained experience in laying out and superintending heavy works, particularly in connection with the crossings of the River Bann by the railway. In July, 1866, he became an Assistant-Engineer on the Belfast Waterworks, which post he held until their completion in October, 1868. In May of the following year he was appointed an Assistant-Engineer on the Intercolonial Railway of Canada, and had charge of the construction of various sections of that line. From June, 1873, to September, 1877, he was engaged as a Divisional Engineer on the Coteau and Ottawa Railway, and on the Montreal, Ottawa and Western Railway.

Mr. Simms returned to Ireland early in 1878, in April of which year he became an assistant to Mr. John Lanyon, of Belfast, for whom he acted as Resident Engineer on the Limavady and Dungiven Railway, the Ballymena Sewerage, and various tramways and miscellaneous works. From June, 1885, to July, 1891, he was employed by the Commissioners of Public Works to superintend the construction of Culdaff Pier, Arklow Harbour, and the Shannon Drainage Works at Killaloe; to hold inquiries and report on drainage and tramway schemes; and to take charge of a section of the Collooney and Claremorris Railway. He was then engaged for six months on the construction of the Westport and Mulrany Railway, the works on which were of a very heavy nature.

In 1892 Mr. Simms took an office in Belfast and endeavoured to obtain work as a consulting engineer. Meeting, however, with but little success, he accepted, in August, 1894, an offer from Mr. John Lanyon to act as Resident Engineer on the Lisburn Waterworks, which post he held until his death, from an internal chill, on the 20th of January, 1896. Mr. Simms was a man of genial and kindly disposition, whose loss is regretted by many friends. He was elected a Member on the 29th of May, 1883.

---

[1] Minutes of Proceedings Inst. C.E., vol. cxxiv. p. 402.

DOUGLAS AUSTHWAITE STANLEY, son of Mr. Edward Stanley, of Ponsonby Hall, Cumberland, for many years M.P. for West Cumberland, was born on the 24th of September, 1838. After serving in the Royal Navy as a midshipman, he was articled in 1859 to the late Mr. John Trevor Barkley, Civil Engineer, and was subsequently employed from 1862 to 1864 on the survey and construction of the Danube and Black Sea Railway and Harbour under that gentleman. From 1864 to 1866 he was engaged on the Varna and Rustchuk Railway, under Mr. William McCandlish, and was then for three years in charge of works on the Giurgevo and Bucharest Railway for Messrs. Brassey, Peto and Co. He was next employed from 1869 to 1871 on the maintenance of the Varna Railway, under the Varna Railway Company, and in 1871 and 1872 on the survey of the western division of the Honduras Railway for Messrs. Waring and Co.

From 1872 to 1876 Mr. Stanley practised on his own account in England, and was afterwards for three years in charge of the survey and construction of the Evesham, Redditch and Stratford-on-Avon Railway, under Mr. Liddell. He was subsequently employed from 1880 to 1884 on the construction of the Minas and Rio Railway for Messrs. Waring and Co., and from 1884 to the date of his death he practised on his own account. During that period he was constantly on the move, visiting Russia, Spain, Portugal, Turkey, Mexico, the United States, Brazil, Egypt, Roumania and South Africa, for the purpose of reporting upon almost every class of engineering undertaking. Mr. Stanley was socially a most agreeable companion and a good sportsman, a man of considerable character, activity and perseverance, most conscientious in the execution of his duties, and highly respected and esteemed by all who knew him. He died at Monte Carlo from the effects of a chill on the 2nd of March, 1896, after a few hours' illness. He was elected a Member on the 1st of December, 1891.

CHARLES COLES ADLEY, second son of the Rev. W. Adley, for thirty-four years Rector of Rudbaxton, Pembrokeshire, was born on the 10th of September, 1828. After being educated at King William's College in the Isle of Man, he was apprenticed to Mr. Edward Highton,[1] Telegraph Engineer to the London and

[1] Minutes of Proceedings Inst. C.E., vol. xix. p. 188.

North Western Railway Company, by whom he was before the expiration of two years appointed a salaried assistant. Having been offered by the Government of India the post of Assistant to Sir William O'Shaughnessy, Director of Telegraphs in India, he left England in 1853. On the voyage out, however, circumstances occurred which induced him to resign the post, and on arriving in India he entered the service of the East Indian Railway Company. After acting for eighteen months as an Assistant Engineer on the Burdwan division, and for a year as Resident Engineer on the construction of the Raniganj division, he was appointed Superintendent of the Telegraph Department of the line.

In 1858 Mr. Adley, in addition to his ordinary duties, founded the *Engineers' Journal and Railway and Public Works Chronicle of India and the Colonies*,[1] published at Calcutta, of which he was the proprietor and editor. He resigned his post on the East Indian Railway in 1862 and returned to England, where he lived for a time on a moderate competency. After the death of his wife, however, Mr. Adley entered in 1868 the service of the Public Works Department of the Government of India. His first duty was the design of the Small Arms Factory at Dum-Dum, in the province of Bengal, and he was highly commended by the Government for the completeness and rapidity of execution of that work. He was then engaged in designing drainage and irrigation works for the improvement of the famine and fever-stricken districts near the banks of the Hooghly. This duty he carried out with such energy that his health suffered materially, and he found himself compelled to resign the service. Mr. Adley then devoted his attention chiefly to mining engineering, and became connected with the Nerbudda Coal and Iron Company and other similar undertakings in India. In consequence, however, of ill-health—he suffered from chronic asthma, the origin of which he attributed to employment in the marshy districts of Bengal—he retired from active work and returned to England in 1873.

Mr. Adley died at Bath on the 11th of April, 1896, in the sixty-eighth year of his age. Up to the last he was a constant contributor to periodical literature on a variety of subjects. He found his favourite recreation in field sports. In disposition he was quiet and unobtrusive. Mr. Adley was elected an Associate on the 1st of April, 1862, and was subsequently placed in the class of Associate Member. In 1852 he had contributed to the Institu-

[1] This journal is in the Library of the Institution.

tion a Paper entitled, "The Electric Telegraph; its History, Theory, and Practical Applications."[1] He was also the author of several pamphlets on telegraphy and other subjects, some of which may be found in the Library.

JAMES SMYTH BENEST, born at St. Helier's, Jersey, on the 26th of March, 1826, was the son of Mr. John Benest. In 1845 he entered the office of Messrs. J. C. Sherrard and Sydney Hall,[2] in Westminster, for whom he was extensively engaged on railway surveys. He then acted as an assistant, under Mr. Joseph Cubitt,[3] on the construction of the Great Northern Railway until 1849, when he obtained an appointment on the staff of the Metropolitan Commission of Sewers. He resigned that post, however, in 1859, to become Borough Engineer of Merthyr Tydfil, where during the next four years he laid out a scheme of drainage, a portion of which he carried out. In 1861 Mr. Benest began to practise on his own account, and in 1865 he was appointed Surveyor to the Commissioners of the River Wensum, at Norwich, which post he held for seven years.

In April, 1872, Mr. Benest proceeded to Rio de Janeiro as Resident Engineer in succession to his brother Edward, on the important drainage works of the Rio Improvements Company. That appointment he resigned in February, 1884, and returned to Norwich, where he remained until his death, from congestion of the lungs, on the 29th of February, 1896. His only engineering work after his return from Rio was at La Palisse (La Rochelle), where he went at the instance of the contractor for the docks then in course of construction, which were opened by President Carnot.[4]

Mr. Benest had considerable skill as an architect and after his retirement gave his services in connection with several works, among which may be mentioned the restoration of Bodham Church, Norfolk, reopened in December, 1892, and the rebuilding of the parish schools at Southwold. His last work was a design for a memorial altar for Holy Trinity Church, Marylebone. His tastes were intellectual and his character was gentle and upright. Mr. Benest was elected an Associate on the 9th of April, 1872, and was subsequently placed among the Associate Members.

---

[1] Minutes of Proceedings Inst. C.E., vol. xi. p. 299.
[2] *Ibid*, vol. lxxix. p. 366. [3] *Ibid*, vol. xxxix. p. 248.
[4] *Ibid*, vol. cxvii. p. 360.

GIULIO CESARE MELISURGO DI MELISSENOS, whose death occurred at Naples on the 7th of May, 1896, was the son of the late Emmanuele Melisurgo, an Engineer, of Bari. The family had originally immigrated into Italy from Greece, had obtained noble rank in the country of its adoption and will be found inscribed in the *Libro d'Oro*. Giulio was born at Paris in 1837 and grew up there till he had practically completed his studies, when he went to Turin, and afterwards, on the death of his father, he proceeded to Southern Italy and was engaged for three years on the construction of the Foggia and Bari Railway. On account of the brigandage in the provinces in those days, this work was accompanied by considerable personal risk. As soon as the line was completed he commenced at Naples that which subsequently proved (though with some interruption) the work of his life, viz., the preparation of a scheme for reclaiming the beach of the Riviera of Chiaia, a stretch of sand between the gardens of what was then the "Villa Reale" and the sea, which was covered both by day and night with a squalid population and was a place of deposit for filth of every description. Mr. Melisurgo was soon, however, moved by a desire to increase his experience, and, actuated by this motive, he returned to France and ultimately went to England, whence he was sent out to aid in the construction of the Argentine Railway from Cordoba to Tucuman. About the year 1875 he settled in London, where he remained for the greater part of ten years engaged in various engineering works chiefly connected with the sanitation of towns. During that time he made constant communications to the Italian press and also contributed to the English technical papers.

It was in 1880 that the distinctly Neapolitan portion of his career commenced, for he returned to Naples in that year and never left it again. The following sixteen years were a period of incessant activity. His work on Sanitary Engineering *Ingegnerie Sanitarie ed Urbane*[1] appeared in 1880, and in the following year he wrote on the project of the Naples to Cuma Railway, which was shortly afterwards carried out. Then came perhaps his most useful book, though it was a small and unpretending crown 8vo. volume, entitled *L'Igiene omicida e gli odori di Napoli*, published in 1882. In the same year he produced a project for the improvement of Castellammare, and between that and 1884 he prepared the plans for the sanitation of Naples, with which his name will be inseparably connected; and though he had the satisfaction of seeing the

[1] This work is in the Library of the Institution.

greater part of the work carried out, he did not, unfortunately, live to see it completed. In 1888 he improved the sanitation of Resina and published a work entitled *Marino Turchi e l'Italia Igienica.* He found time to occupy the Chair of Hygiene in the University of Naples, and from 1884 he was a member of the Technical Council of the Naples Municipality. During this period he took a leading part in making the new port of S. Lucia and the Caracciolo Embankment, besides assisting in the building of a house for Mr. Crispi, and in designing entirely a villa in the Pompeiian style for Prince Linguaglossa, Mr. Crispi's son-in-law.

Mr. Melisurgo was elected an Associate on the 29th May, 1877, and was subsequently placed in the class of Associate Member. He was also connected with numerous foreign societies. He married an English lady from Leamington, who survives him. In Giulio Melisurgo the public of Naples has lost an efficient and able adviser, and the British community an excellent and hearty friend.

HENRY PARNHAM PHILLIPS, second son of the late Mr. L. Parnham Phillips, of Wendover, was born on the 26th of October, 1856. He was educated at Bedford, where he distinguished himself as an athlete, excelling in cricket and football. In September, 1873, he entered the London and North Western Railway works at Crewe as an apprentice, and after passing through the shops and drawing-office served for nearly four years as a locomotive foreman, first at Holyhead and then at Stafford. He next became, in January, 1883, Assistant Manager at Messrs. Sharp, Stewart and Company's works, Manchester, where he remained until the following December, when he was appointed Manager of the shops of the Scinde, Punjab and Delhi Railway at Lahore, under Mr. Charles Sandiford, the Locomotive Superintendent of that line.

Mr. Phillips held that post for six months, when he became Assistant Locomotive Superintendent of the Burma State Railways, and for some years lived near Rangoon. In 1893 he contracted severe fever, the result of a long day's snipe shooting in the marshes, and from that time his health gradually broke down. Although a prolonged stay in Switzerland benefited him temporarily, his return to India was followed by a renewal of his old complaint. He finally journeyed to South Africa, and, when getting stronger, was attacked by influenza. A form of pneumonia supervened, to which he succumbed, quietly and painlessly, at Bloemfontein, on the 30th of March, 1896. Mr. Phillips was an

ardent sportsman, being an exceptionally good shot. Those who got beneath his reserved and reticent manner, discovered his genuine worth, and esteemed him as an able engineer, and an honourable man. He was elected an Associate Member on the 4th of April, 1886.

JOHN SINCLAIR PIRRIE, born on the 3rd of May, 1849, was educated at the Royal Belfast Academical Institution, at Queen's College, Belfast, and at the Polytechnikum of Stuttgart. In February, 1869, he entered the service of Messrs. Combe, Barbour, and Combe, mill engineers of Belfast, with whom he remained until August of the following year, when he obtained an appointment in the works of Messrs. Harland and Wolff, of Belfast. He was then employed by Messrs. James Jack and Company, of the Victoria Engine Works, Liverpool, and by Messrs. Laird Brothers, of Birkenhead.

In 1874 Mr. Pirrie proceeded to Brazil, where he was engaged for two years in erecting piers, wharves and machinery on the Amazon for the Brazilian Government. He was then twelve months at Manila in the service of the Spanish Public Works Department, and for two years Resident Engineer in Bombay for the New Colaba Land Reclamation Company. In 1879 Mr. Pirrie was appointed managing director of the Carnac Ironworks Company, Bombay, and in that capacity he designed and carried out many large works for the Government of India and for some of the native states. In 1889 he proceeded to Australia, where he became one of the Managers of the Austral Otis Engineering and Elevator Company. That post he held until his death, from heat apoplexy, on the 25th of January, 1896, at Tarnegulla, Victoria. Mr. Pirrie was elected an Associate Member on the 2nd of December, 1884.

DAVID THOMAS RHYS PROTHEROE, born on the 30th of June, 1856, commenced his engineering career in 1872 as a pupil of Mr. Benjamin Lawrence, of Newport, Mon., with whom he subsequently remained as an assistant. He was then engaged from May, 1879, to October, 1880, on drainage work for Mr. Edward F. Griffith, of Westminster, after which he was employed for two years under Mr. Alfred Williams in preparing drawings for, and in assisting to carry out, part of the Chislehurst and Crays Valley drainage for the Bromley Rural Sanitary Authority.

In 1882 Mr. Protheroe became Chief Assistant to Messrs. Gotto and Beesley, and on Mr. Gotto retiring from the firm in 1890, he remained with Mr. Beesley for two years in a similar capacity. During that time he was engaged in preparing contract drawings for drainage works at Rio de Janeiro, the drainage and water-supply of Campos (Brazil), and the drainage of Brentford, Chatham, Cheshunt, Hayes and other places. Mr. Protheroe resided from 1893 at Fleur-de-lis, near Cardiff, where he died on the 2nd of April, 1896. He was elected an Associate Member on the 12th of January, 1892.

JAGANNATH SADASEWJEE, born on the 2nd of November, 1826, was educated at the Elphinstone College, Bombay, and from 1844 to 1847 studied there in a class of engineering, to which Mr. W. Pole had been specially sent out from England as Professor. In this class Mr. Sadasewjee proved a very promising pupil. In September, 1848, he entered the Public Works Department of the Bombay Presidency, and was employed at Poona in surveying, estimating, and construction work, being soon recommended for promotion to the grade of Assistant Engineer. He was then appointed—under the Bombay Municipality—as an assistant to the late Mr. Henry Conybeare, who was at that time engaged on the Vehar Waterworks,[1] and who, in a testimonial dated the 30th of March, 1855, spoke in high terms of the manner in which Mr. Sadasewjee assisted him in preparing a report on that important undertaking.

In 1856 Mr. Sadasewjee was appointed Municipal Surveyor of Karachi, which was then a rising port. Among the works which he designed and carried out in that capacity may be mentioned the Elphinstone Bridge, and the improvement of the water-supply. He also devoted much of his time to instructing the Engineering class, established by the Government at Karachi.' The improvement of the Harbour of Karachi by the construction of the Manora Breakwater and other important works,[2] from the designs and under the superintendence of Mr. W. H. Price, was commenced in 1860. Mr. Sadasewjee was engaged on that arduous undertaking and was highly commended by Mr. Price for his energy and zeal, and as having been "successful in devising the means of overcoming many difficulties encountered in the progress of the works, thereby,

[1] Minutes of Proceedings Inst. C E., vol. xvii. p. 555.
[2] *Ibid*, vol. xliii. p. 1.

in more than one instance, effecting important saving." On the commencement of the dredging operations in the New Channel, he was chiefly occupied in the management of the work of landing the spoil, as well as in making out the lines for dredging and excavation, and in superintending the latter work, which was performed by hand-labour.

Mr. Sadasewjee resigned his appointment in the Public Works Department in 1862, to enter into partnership in the firm of Dinshaw, Jagannath & Co., contractors. Amongst other works, this firm constructed the Karachi-Kotri division of the Sind Railway. In 1865 he again took service under the Bombay Municipality as an Assistant Engineer, in which capacity he rendered material aid in connection with the scheme for the main drainage of Bombay and in the preparation of a report on the extension of the Vehar Waterworks. Mr. Sadasewjee then became an Assistant Engineer on the staff of the Great Indian Peninsula Railway Company, after which he served as Local Fund Engineer in Khandesh. On the recommendation of the late Mr. Thomas Ormiston,[1] the Engineer to the Bombay Port Trust, he was engaged by the Kutch Durbar, to construct a pier at Mandvi, a work which he successfully carried out, with great advantage to the trade of that port.

Mr. Sadasewjee's next and last appointment was that of Executive Engineer to the State of Baroda. His chief work in that capacity was the design of a complete system of water-supply for the city of Baroda, including the construction of an impounding reservoir, 12 miles north-east of Baroda; a 30-inch cast-iron main; settling tanks and purification-works; and a covered-service reservoir and distribution-works. In the flat, alluvial country, of which the eastern portion of the Baroda territory consists, it was a difficult problem to secure an adequate supply of water by natural collection, the delivery of which should be dependent on gravitation only, while the material available for the embankments was little better than sand and mud. Mr. Sadasewjee, however, brought the works to a successful completion, to the great sanitary advantage of the crowded city of Baroda. In a Paper[2] read before the Institution in November, 1893—in conjunction with accounts of the Tansa (Bombay) and Jeypore Waterworks—he gave a detailed description of the undertaking.

On the completion of these works, Mr. Sadasewjee was directed to make plans for the drainage of the city of Baroda, and, with

[1] Minutes of Proceedings Inst. C.E., vol. lxxi. p. 409.
[2] *Ibid*, vol. cxv. p. 43.

that object in view, to visit Calcutta and Rangoon for the purpose of examining the results of the Shone system there in operation. While thus engaged, it became apparent that the exertion and exposure he had undergone during the construction of the Baroda Waterworks had seriously impaired his health. He went to his native city of Bombay for rest and change; but paralysis had shown itself and he died there on the 26th of March, 1896.

Mr. Sadaswejee was a man of quiet habits and unobtrusive character, and was greatly respected by all with whom he was associated. His energy and painstaking assiduity were highly commended by those under whom he served. He was elected an Associate on the 14th of January, 1868, and was subsequently placed in the class of Associate Member.

GEORGE PARKER BIDDER, M.A., Q.C., was born on the 18th of August, 1836, in London. He was the eldest son of George Parker Bidder, [1] known from boyhood for his powers of mental calculation and who was President of the Institution in 1860 and 1861. The subject of this notice was educated first at King's College School and at the University of Edinburgh, where he gained distinction in the mathematical classes under the late Professor Kelland. Passing to Trinity College, Cambridge, he obtained a scholarship there, and in 1858 graduated as seventh wrangler. Two years afterwards he was called to the Bar at Lincoln's Inn and joined the Home Circuit, his success as a Junior being marked and rapid. He was Counsel for a large scheme originally proposed for the Forth Bridge by Sir Thomas Bouch, which was reported upon by Mr. W. H. Barlow and Dr. Pole in 1873, and his conduct of that case determined the course of his subsequent career. This lay mainly among Parliamentary Bills, arbitrations, and compensations, involving engineering, scientific or statistical evidence. Clear and lucid statement, easy exposition of intricate argument, that mastery of evidence and "first principles" which makes cross-examination so effective, were the weapons with which Mr. Bidder achieved his success. The rapid calculation of his father in the witness-box was one of the puzzles to parliamentary counsel of the last generation; the same power, in the son's hand, has proved perturbing to more than one engineering witness of later date, and he is perhaps best known for successful contest with expert evidence, alike in the box and in the convincing analysis of his subsequent

[1] Minutes of Proceedings Inst. C.E., vol. lvii. p. 294.

speech. Perhaps one of his greatest triumphs was in "The Metropolitan Board of Works *v.* The Millwall Dock Company" (1876), a case which turned on the laws of deposit and silting in rivers; better known is his masterly and effective opposition for the Mersey Docks and Harbour Board against the Manchester Ship Canal, based mainly on the theory of the formation and erosion of banks in an estuary. In the inquiry into the collapse of the Tay Bridge he successfully defended the reputation of its engineer, the case involving the closest study of every technical detail. The later Forth Bridge Bills were entrusted to him, and he was Counsel for the Metropolitan Board of Works against the Thames Conservators, a case largely depending, like that of the Millwall Dock and the Manchester Ship Canal, on the laws of flow and deposition of suspended matter, but also on elaborate arguments from chemistry and biology. He appeared for some twenty-eight years in all the Bute Dock, Midland, North-Eastern and most of the District Railway cases, and held general retainers for the Midland, North British and Brighton Railways, the Mersey Dock Board, the Marquis of Bute and the Bute Dock Companies. He was also standing counsel for more than one of the great water companies. The last case in which he appeared was one for compensation against the Great Eastern Railway Company, and his speech, on the Saturday before he died, was considered exceptionally able. He took silk in 1874 and shortly afterwards became a bencher of Lincoln's Inn, standing at the time of his death next in rotation for the annual office of Treasurer.

It is of more than personal interest to compare Mr. Bidder's special gifts with those of his father. In a letter published in the *Spectator* of 28th December, 1878, he says of the latter:—

"In my opinion he had an immense power of realising the actual number. . . . He was aided, I think, by two things—first, a powerful memory of a peculiar cast, in which figures seemed to stereotype themselves without an effort; and secondly, by an almost inconceivable rapidity of operation. I speak with some confidence as to the former of these faculties, as I possess it to a considerable extent myself (though not to compare with my father). Professor Elliot says he (my father) saw mental pictures of figures and geometrical diagrams. I always do. If I perform a sum mentally, it always proceeds in a visible form in my mind; indeed, I can conceive no other way possible of doing mental arithmetic. The second faculty, that of rapid operation, was no doubt congenital, but developed by incessant practice, and by the confidence thereby acquired. . . . With my father, as with myself, the mental handling of numbers and playing with figures afforded a positive pleasure and a constant occupation of leisure moments. . . . It is also worthy of record that my father had an enormous store of facts, formulas, and constants relating to all manner of geometrical questions and physical subjects, which were always available for the ready solution of

problems, either in pure mathematics, or in the application of mathematics to mechanics, hydraulics, &c. In my opinion, this is a kind of knowledge which is not half appreciated. I have found continually immense advantage in having formulas and constants ready to hand. . . . I myself can perform pretty extensive arithmetical operations mentally, but I cannot pretend to approach even distantly to the rapidity and accuracy with which my father worked. I have occasionally multiplied fifteen figures by fifteen in my head, but it takes me a long time, and I am liable to occasional errors. Last week, after speaking to Professor Elliot, I tried the following sum, to see if I could still do it:—

378,201,969,513,825 × 199,631,057,265,413.

And I got in my head the answer:—

75,576,299,427,512,145,197,597,834,725,

in which I think, if you take the trouble to work it out, you will find four figures out of the twenty-nine are wrong."

The final statement at first sight seems to contradict the claim for great inferiority to his father in arithmetical gifts. But the method of calculation explained to the Institution by Mr. Bidder in 1856[1] was not followed by the son when the number of significant figures was large. For such cases he employed a method which, although inapplicable without powers of numerical conception and realisation, yet enormously increased their scope and effect. Briefly, the two numbers to be multiplied and the answer as obtained, were recorded by a simple *memoria technica* ("Gray's") as letters of the alphabet or diphthongs, and the answer was obtained from right to left, as in ordinary paper arithmetic.[2]

---

[1] Minutes of Proceedings Inst. C.E., vol. xv. p. 251.

[2] Thus, treating for example two small numbers by the method which would be employed for larger ones, multiplication would be effected as below [for comparison the numbers chosen are those multiplied at length by the elder Mr. Bidder in the discourse referred to]. In the memory system employed there are ten vowel sounds and ten consonants, one of each class for each numeral:—

397 × 173, recorded as "toup" × "boit."

(1) $3 \times 7 = 21$; 1 and carry 2; 1 recorded as "b";

last figure of answer recorded as "b."

(2) Carried 2;

$3 \times 9 = 27$, and $2 = 29$;
$7 \times 7 = 49$, and $29 = 78$; 8 and carry 7; 8 recorded as "ei";

last two figures of answer recorded as "eib."

(3) Carried 7;

$3 \times 3 = 9$, and $7 = 16$;
$7 \times 9 = 63$, and $16 = 79$;
$1 \times 7 = 7$, and $79 = 86$; 6 and carry 8; 6 recorded as "s";

last three figures of answer recorded as "seib."

Mr. Bidder often remarked that the method pursued by those of very great numerical gifts, such as his father, necessitated a far more severe mental operation, since there had always to be carried in the mind a perpetually fluctuating number of the order of magnitude of the final answer,[1] whereas multiplying as on paper every figure obtained is final. He was wont to lay down the rule that to facilitate mental calculation, every operation, where possible, should take the form of division. Mr. Bidder, the elder, said:—"Division is, in mental, as in ordinary arithmetic, much more difficult than multiplication."[2] If followed out, these two statements will be found to well illustrate the essential difference between the two methods.

Multiplying billions by billions accurately to the twenty-ninth place has no value except as a form of mental athletics. Such athletics, however, produced in the Queen's Counsel, as formerly to a greater degree in the engineer, a knowledge of numbers of the highest practical importance, causing the ordinary calculations occurring in daily life to present themselves instantaneously in forms of almost spontaneous solution. In addition to this, the

---

(4) Carried 8;

$7 \times 3 = 21$, and $8 = 29$;
$1 \times 9 = 9$, and $29 = 38$; and carry 3; 8 recorded as "ci";

last four figures of answer recorded as "eiseib."

(5) Carried 3;

$1 \times 3 = 3$, and $3 = 6$; 6 recorded as "s."

Answer recorded as "seiseib" = 68,681.

It will be seen that at any moment there are held in the memory three articulate nonsense words, and at the most two comparatively small numbers; the nonsense words are never changed during the process except by prefixing fresh letters to that representing the answer. The word is recorded on the memory as a visible, an audible and a speakable imagination; the memory being also guided by its relationship to significant words, precisely as in the recollection of a proper name read for the first time. Its letters are thus stereotyped in a block, in which they can be examined singly at will. Thus, while not refuting "the necessity of keeping only one result before the mind at a time," pointed out in the discourse of Mr. Bidder, sen., the operator is enabled to retain the three principal numbers without acute consciousness of them, while actively employed on a subsidiary operation of comparatively small difficulty.

It would seem that the method should be practically used only within the limits of certain freedom from error, since error is as likely to occur among the left-hand as among the right-hand digits of the answer.

[1] Minutes of Proceedings Inst. C.E., vol. xv. p. 260.

[2] *Ibid*, vol. xv. p. 264.

actual material of such athletics was mainly those "facts, formulas and constants" above referred to, which were thus not only perpetually receiving additions, but perpetually becoming more and more familiar and ready to the mind.[1] In 1890 he added some explanations and remarks to a Paper contributed to the Proceedings of the Institution by Dr. W. Pole, describing the mode of calculating logarithms mentally adopted by his father.[2] Mr. Bidder hated to feel dependent on works of reference for any constants or formulas, and it was one of his greatest powers, perpetually utilised, that he could almost always remember data and devise a method to form a rough and rapid estimate of any calculable quantity. In cross-examination especially, this power furnished a valuable weapon, for the figure given by an expert presented rapidly to his mind its long train of consequent figures, branching all over the case in his charge and crossing or coinciding as might be with the lines traced by evidence from other sources already obtained or obtainable.

He was very fond of mechanics as a diversion and used to amuse himself by designing little suspension-bridges for his trout-stream; two of which—one, with the tension-members beneath the roadway, of light and graceful design—were erected from his drawings and are in use. In the "Monthly Notices of the Royal Astronomical Society"[3] will be found the account of a new form of position micrometer, devised by him for the telescope and always used by him in double-star measurements. He invented an ingenious modification for increasing the delicacy of the chemical balance, and used to spend hours in filing brass and in polishing agates; for in the workshop, as with calculations, he hated to be compelled to use a ready-made article. But perhaps his most favourite intellectual recreation, besides the construction of easy formulas for mental calculation, was the study of ciphers.

---

[1] As a simple instance may be quoted a method, the invention of which pleased him much many years ago, for calculating rapidly the squares of numbers under 100:—

$$N^2 = (N - 25)\,100 + [25 - (N - 25)]^2$$
$$\text{Ex.—}49^2 = (24)\,100 + [25 - 24]^2$$
$$= 2{,}400 + 1 = 2{,}401;$$

everyone, of course, knowing the squares of numbers up to 25. Formulas for vital statistics, for compound interest problems, for the formation of a calendar of the sun's altitude, were the frequent subjects of his recreation; and it may be said that there was no series of facts with which he was familiar for which he had not devised, and generally remembered, some ready-reckoning process.

[2] Minutes of Proceedings Inst. C.E., vol. ciii. p. 250.

[3] Vol. xxxiv. p. 394.

He early published an article[1] on their general principles and from the latest advertisement in *The Times* to seventeenth-century State Papers, he was to the end of his life never tired of pitting his ingenuity against that of the man who believed concealment insoluble and rarely succeeded in preserving it.

Mr. Bidder took a prominent part (as Chairman of the Cannock Chase Colliery Company) in the great coal strike of 1893, and was a member of the body of coal-owners which, under Lord Rosebery's presidency, met the representatives of the colliers. He published at this time a valuable article on the economics of a coal-mine,[2] pointing out the importance of quantity in coal-mining, as opposed to price, on account of the heavy fixed expenses which are unaffected by diminution of output. His mastery over figures was greatly valued by his colleagues of the Cannock Chase Colliery Company, of the Danish Gas Company (of which he was Chairman) and of the Rock Life Assurance Company. He was on the County Council and Commission of the Peace for Surrey, and was a considerable benefactor to Mitcham, where he resided, especially in the continuous protection of Mitcham Common, for which he ultimately obtained an Act fairly assuring its future. Among other instances in which he helped to preserve the property of the community may be mentioned his successful defence of the right-of-way along a beautiful path near Dartmouth to Compass Cove. He was a pioneer of the Charity Organization Society, and took great interest in all that tended to increase the liberty and well-being of the less wealthy classes. While he lived in London he served as almoner at Stepney, working there through a severe cholera epidemic.

Mr. Bidder was a keen fisherman and golf-player, and in 1867 was fourth for the Queen's Prize at Wimbledon. In physique he was robust, capable alike of great concentration and of prolonged exertion. In character he was always courageous, never spared himself, and gave freely of time, money or labour for the public good or in private kindness; he was much loved by very many friends. Stern conscientiousness and strong combativeness were the qualities most known in his public relations. Those intimate with him will remember as vividly a boyish lightness of spirit, a fresh versatility of culture and a sincere reverent piety.

Mr. Bidder was elected an Associate on the 3rd of December, 1861. A few months previously he had contributed to the

---

[1] *Macmillan's Magazine*, February, 1871.

[2] *Nineteenth Century*, vol. xxxv.

Institution a Paper entitled "The National Defences,"[1] for which he was awarded a Telford Medal and a Manby Premium. He was also an Associate of the Surveyors' Institution and a Fellow of the Royal Astronomical Society. He married in 1860 Anna, daughter of Mr. J. R. McClean,[2] M.P., F.R.S., President of the Institution in 1864–65. He died at Queen Anne's Mansions, Westminster, in the full tide of ability and success, on the 1st of February, 1896, quite unexpectedly, from the effects of a street accident in Manchester three weeks previously. It was characteristic that the day after he had been run over, rather than necessitate the inconvenience to so many people of coming together again at a future date, he conducted cross-examinations for six hours, though suffering acutely.

MAJOR-GENERAL SIR JAMES BROWNE, R.E., K.C.S.I., C.B., who died at Quetta, Baluchistan, on the 13th of June, 1896, was the son of Mr. Robert Browne, of Falkirk, N.B. He was born on the 16th of September, 1839, and, was educated abroad and at the Military College, Addiscombe, obtaining a commission in the Bengal Engineers in 1857. In 1860 he served with the expedition against the Mahsud Waziris on the North-West frontier of India, being present at the storming of the Burera Pass and at the capture of Kaneegurum and Mukeen. For this he was mentioned in despatches and received a medal with clasp. He then acted for a time as Assistant Engineer on the construction of the road between Lahore and Peshawar. In 1863 he served in the Umbeyla campaign and greatly distinguished himself, being three times mentioned in despatches and receiving the brevet of Major. It was during the period from 1860 to 1864 that he laid the foundation of that colloquial knowledge of Pushtu and Persian which proved so useful in his subsequent career.

In 1864 Major Browne took a short furlough to England, when he married Alice, the daughter of Mr. C. Pierson. On his return he was sent to open out and construct roads in the hill district of Kangra in the Punjab. His work there added greatly to his reputation, some of his bridges especially being distinguished by their great span and boldness of design. In 1869 he again took furlough, part of which he spent in studying the best examples of iron bridge construction in England, America, and Holland.

---

[1] Minutes of Proceedings Inst. C.E., vol. xx. p. 391.
[2] *Ibid*, vol. xxxviii. p. 287.

On his return to India in 1871 he was placed in charge of the hill station of Dalhousie in the Punjab. In 1875 and 1876 Major Browne was employed under Sir Guilford Molesworth in designing iron bridges, including that for the Indus Valley Railway at Sukkur, and in 1877 he was deputed by Lord Lytton, the then Viceroy, to prospect for the most suitable line of railway from Sukkur to Quetta. With the thoroughness which characterised all he did he obtained a complete knowledge, not only of that wild country, which, with the exception of the Bolan Pass, was practically unknown to Europeans, but also of the tribes inhabiting it over whom he exercised extraordinary influence. In the same year he was promoted to the rank of Lieutenant-Colonel.

In the Afghan war of 1878–79, Colonel Browne served as Political Officer to Sir Donald Stewart's division, his knowledge of the language and intimacy with the head men of the Gilzai and other tribes being of the greatest value in obtaining information and supplies. He took part in the engagement at Takht-i-Pul, and in the advance to Kandahar, being several times mentioned in despatches, and receiving the medal and the Companionship of the Order of the Star of India. In 1881 he was promoted Colonel, and in the following year he was appointed Personal Assistant to the Inspector General of Military Works, and subsequently to the Chief Engineer and Secretary of the Punjab Government. When the Egyptian war of 1882 was undertaken, he was selected by Sir Donald Stewart, then Commander-in-Chief in India, to command the Royal Engineers of the Indian contingent, and was present at the battle of Tel-el-Kebir. For this service he received the medal with clasp, the Companionship of the Order of the Bath, the 3rd class of the Order of the Osmanieh and the Khedive's star.

On returning to India, Colonel Browne was placed in charge of the Hurnai Railway, which, for some 200 miles, runs through the mountains of Baluchistan, and connects Quetta with the railway system of the plains of India. During the progress of that work, besides the onerous duties of Engineer-in-Chief, he held command of all the troops on the line—about 3,000 men—with the rank of Brigadier-General. On the completion of the Hurnai Railway, he took a well-earned rest in England in 1887. In the following year he was created a Knight Commander of the Order of the Star of India. The Hurnai railway was Sir James Browne's last engineering work, for, in 1889, he was appointed Quarter-Master-General in India. In 1892 he succeeded the late Sir Robert Sandeman as Governor-General's Agent and Chief Commissioner in Baluchistan, which post he held at the time of his death.

Sir James Browne was a man of splendid physique and great

bodily strength, which no doubt had much to do with his influence among tribes, in whom a strong hand, daring courage, and unswerving resolution at once inspire respect; but even these can hardly account for the immunity with which he moved, unattended by the heads of tribes, among wild fanatics, who believe that to kill a Kafir is a sure road to Paradise.[1] He himself was inclined to attribute that immunity to his extraordinary resemblance to an influential Mullah (Mohammedan priest), who at one time lived at Mukkur amongst the Gilzais and suddenly disappeared in 1878. Sir James Browne knew every inch of the country he ruled over and understood the people, who felt that he was a firm and upright official, from whom unflinching justice, tempered with sympathy for those he governed, might be obtained. He was elected an Associate on the 5th of December, 1871, and three years later he presented to the Institution a Paper "On the Tracing and Construction of Roads in Mountainous Tropical Countries,"[2] for which he was awarded a Telford Premium.

JOHN CLUTTON[3] was born on the 29th of August, 1809, at Hartswood in the parish of Buckland, Surrey, where his father, Mr. William Clutton, carried on a large and successful business as a land agent. The subject of this notice was educated at a Grammar School at Cuckfield and subsequently at a preparatory school at Clapham. He was originally intended for the law, but his father wanted his assistance and that of his brother Robert at Hartswood, and there he remained ten years, making himself acquainted with every detail of the business and laying the foundations of that knowledge of farming and forestry which was to prove of such great service in his subsequent career.

In 1837 he married and came to London, taking a small house, which served as office also, in the block of buildings on the west side of Parliament Street, pulled down many years ago to widen the roadway and make room for the new public offices. Here he remained until his removal to Whitehall Place in 1844. During these six and a half years he was principally occupied with the land purchases for the construction of various sections of the

---

[1] *Blackwood's Edinburgh Magazine*, August 1896, contains a graphic and interesting narrative entitled, "A Strange Episode in the Life of Major-General Sir James Browne, K.C.S.I., C.B., R.E., related by himself, with a sketch of his services by Major W. Broadfoot, R.E."

[2] Minutes of Proceedings Inst. C.E., vol. xxxviii. p. 67.

[3] This notice has been abridged from one which appeared in the Transactions of the Surveyors' Institution, vol. xxviii. p 478.

South Eastern Railway. In these and other railway surveys and land purchases, together with the conduct of one or two small estates agencies, Mr. Clutton found abundant employment during the first six years of his life in London, but in consequence of the rapid increase of his business it soon afterwards became necessary to take a larger house, and there being a prospect of considerable employment arising from an introduction to the Ecclesiastical Commissioners, he determined to remove to No. 8 Whitehall Place, in the immediate vicinity of their offices.

At this time there was vested in the Ecclesiastical Commissioners, chiefly in reversion only, a very considerable quantity of land and other property which had belonged to non-residentiary prebends and to deaneries of cathedral churches of the old foundation, and additional property was constantly falling in as lives lapsed, but the only knowledge which the Commissioners then possessed as to the particular extent, nature and value of these properties, was such account of them as could be furnished by the Chapter Clerks of the respective cathedrals and collegiate churches. About 1845 it had become manifest to the Board that it was of primary importance to procure, with all possible despatch, particulars, surveys, estimates and reports on the various lands and properties vested in the Board, and that these should be prepared by and obtained from experts on whom the greatest reliance could be placed. This work, throughout the southern half of England and Wales, was entrusted to Messrs. Robert and John Clutton. The business connected with the Ecclesiastical Commission rapidly assumed, to use Mr. Clutton's own words, "a gigantic character," and necessited a large increase of his staff. Later on, about 1856, his brother, Mr. Henry Clutton, joined the firm and took the management of the agencies connected with the Ecclesiastical Commission work.

In March, 1848, a Select Committee was appointed to enquire into the expenditure and management of the Department of Woods and Public Buildings—functions which remained thus strangely assorted until 1851. Mr. Clutton was apparently first invited to report to the Commissioners of Woods, &c., early in 1848, and in conjunction with his brother Robert, in February, 1849, received instructions to proceed to the New Forest, and after viewing the lands, woods, and plantations, to report to the Department the "best opinion they could form upon such inspection as the time and circumstances would permit." Within a few hours of their return and before their report could be written, they were summoned to give evidence before the Committee. Mr. John Clutton

only was examined, his brother simply confirming his evidence. A little later on he was called to give evidence with reference to the Forests of Dean, Bere and Parkhurst. In all this evidence Mr. Clutton's characteristics were fully displayed. It was clear that he intended to demonstrate, and succeeded in doing so, that where-ever the Department had a free hand and was unencumbered by impracticable conditions rendering a sound system of forestry impossible, the management had been both skilful and judicious. As the result of the enquiry, a change was shortly afterwards made in the constitution of the Department, which became the "Office of Woods, Forests, and Land Revenues of the Crown." The Receivership of Crown rents for the county of Surrey falling vacant a little later on, Mr. Clutton was recommended for the appointment by Mr. Gore, one of the Commissioners, who had been struck with his professional sagacity, especially in questions of wood management. In 1851 he was made Crown Receiver for all the Midland and Southern counties of England, the Royal Forests excepted. In 1887 the counties of Norfolk and Suffolk were added to his receiverships. He continued to act as Crown Receiver up to August 1889, when he retired from the position; but, in April 1890, he again gave evidence before the Parliamentary Committee of 1889–90 on the Woods, Forests and Land Revenues, respecting the management of the Crown estates which had been under his charge. Under his advice a great deal was done towards the consolidation of the Crown estates by the sale of outlying or scattered properties and the purchase of compact estates, or of properties adjacent to other Crown estates. The Crown revenue was also largely improved by the development of building estates, notably at Richmond (Surrey), Eltham and Windsor, and the good results of his management may be seen in the present condition of the woods at Esher (Surrey) and at Hazleborough and Salcey in Northamptonshire.

There remain one or two matters of a more general character to which reference should be made. First among these is the important share which he took in the establishment of the Surveyors' Institution, on the formation of which, in July, 1868, he was selected as its first President and served the office for two consecutive years. Enough has been said to show the wide range of Mr. Clutton's activities between the year 1837, when he came to London, and the year 1889, when, owing to advancing age, he retired from active business. His last years were spent in the neighbourhood of Reigate, to which he turned with affection in his old age, and where he died on the 1st of March, 1896, in his eighty-sixth year

Conspicuous success in any vocation is usually associated with the possession of striking abilities. Mr. Clutton would have been the first to disclaim any pretensions to special talent. He neither wrote nor spoke with ease, and his expository powers were very inferior to his powers of apprehension. The technicalities of an Act of Parliament were a perfect bugbear to him. What he did possess, and that to an extraordinary degree, was the solid practical business faculty which makes directly for success in life. This faculty, in union with a calm temperament, great sobriety of judgment, a firm will and a large amount of natural caution, were the principal qualities which he brought to the building up of his vast business. But he had other noticeable characteristics allied to these and almost as useful to him. He was chary of speech, but his habitual reticence sat well upon him and never gave the notion of suppression or concealment. He had the art of leading where he appeared to follow. He made no profession of knowledge, but it was dangerous to assume that he was ignorant, for he had a knack of suddenly transposing the *roles* of teacher and learner. He possessed in an eminent degree the art of conciliating opposition and allaying jealousies. In his relations with his brother surveyors he was frankness itself. His stores of knowledge were ever at their disposal. No young man hesitated to seek his advice or went away disappointed. To show the reliance placed in his probity instances could be cited in which the surveyor on "the other side" unreservedly left the determination of price to his decision, in full confidence that he would do nothing unjust, even in his client's interest.

This imperfect sketch would be incomplete without some reference to Mr. Clutton's really remarkable powers as an organiser. His ordinary agencies were numerous enough to severely tax the powers of most men, to say nothing of the large general practice as a surveyor which he carried on for many years. Add to this his Crown Receiverships and his work in connection with the Ecclesiastical Commission, and it is to be wondered how a single mind could have borne the weight of so much responsibility. Indeed, it would have been impossible except for the perfection of the organisation which he created for the purpose, and the sagacity with which he selected the heads of the various departments of his business. He adopted the principle of all but absolute devolution to the persons so selected, treating them as personal friends and social equals, with the result that they regarded his interests as theirs and the credit of the house as their credit. Thus the thousand and one details which

entered into each day's work fell at once into their proper place in a general system where the controlling mind could be constantly felt without being constantly consulted. Mr. Clutton was remarkably free from ostentation. His personal habits were of the simplest. He loved his home, which was endeared to him by one whom he has himself described as "a pattern to all women," and it may be questioned whether he was ever so happy as in the simple rural surroundings amid which he was born and bred, walking about spud in hand over his land or going the round of his farm-buildings at Flanchford.

Mr. Clutton's connection with the Institution extended over nearly fifty-six years. He was elected an Associate on the 10th of March, 1840, and in the year 1848 he served on the Council. He was also a Member of the Royal Agricultural Society from 1838 and was elected a Foundation Life Governor in 1890.

*** The following deaths have also been made known since the 2nd of June, 1896:—

Honorary Member.

GROVE, *The Right Hon. Sir* WILLIAM ROBERT, M.A., D.C.L., LL.D., F.R.S.; *born* 11 July, 1811; *died* 1 August, 1896.

Members.

CAIRNS, ANDREW DUNCAN; *born* 28 September, 1850; *died* 7 May, 1896.

CARRINGTON, THOMAS; *born* 5 October, 1841; *died* 27 June, 1896.

CUNNINGHAM, DAVID; *died* 13 June, 1896, *aged* 57.

DORNING, ELIAS; *died* 18 July, 1896, *aged* 77.

Associate Members.

BANKS, EDWARD NEVILL; *born* 7 May, 1845; *died* 17 April, 1896. (*Rupture of a blood vessel.*)

HEARNE, EDWARD BERESFORD, M.E.; *born* 13 October, 1854; *died* 23 April, 1896. (*Rupture of a blood-vessel on the brain.*)

HINDS, HERBERT; *born* 10 December, 1864; *died* 16 June, 1896. (*Drowned at the foundering of the "Drummond Castle."*)

ROY, NORMAN WILLIAM; *born* 1 October, 1862; *died* 10 May, 1896. (*Malarial fever.*)

WHEELER, WILLIAM HERBERT, B.A.; *born* 11 May, 1867; *died* 28 June, 1896. (*Drowned off Skegness while yachting.*)

Associates.

KENNARD, Howard John; *died* 8 August, 1896, *aged* 66.

PRESTWICH, *Sir* JOSEPH, M.A., F.R.S.; *born* 12 Mar., 1812; *died* 23 June, 1896.

TREVOR, *Maj.-Gen.* JOHN SALUSBURY, C.S.I., *late* R.E.; *born* 1830; *died* 9 June, 1896.

Information as to the professional career and personal characteristics of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., 10 August, 1896.

Sect. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

The Employment of the Lemniscate of Bernouilli for Transition Curves. By Paul Adam.

(Annales des Ponts et Chaussées, October, 1895, p. 383.)

Transition curves on railways—from the straight to the circular—are generally formed by means of a cubic parabola, but in 1892 Maximilien de Leber pointed out that this curve does not give very exact results with circles of small radius, and he suggested the use of curves—which he calls "radioids"—satisfying the equation:—

$$\rho = \frac{C}{x},$$

where ρ = radius of curvature,
C = a constant, being a function of the speed of the train and the gradient necessary to give the super-elevation required,
and x = either the arc, the chord or the abscissa of the transition curve.

The three curves, obtained by giving x these three values, vary inappreciably in the short portion near the origin required for transition curves, and the Author devotes this Paper to showing that the second case—where x is equal to the chord of the curve, giving the double lemniscate of Bernouilli—is very suitable for transition curves, giving more exact results than the cubic parabola, while its application in practice is quite as simple.

The Paper first deals with the setting out of curves in the original construction of railways, and the Author considers the two methods of inserting transition curves: firstly, by altering the position of the centre of the circular curve while retaining the radius unaltered, and secondly, by reducing the radius while retaining the same centre. The former method gives simpler results; as in that of the reduced radius, the required value must be obtained by successive approximations. The Author gives examples of the calculations for a lemniscate transition curve, first for an unaltered radius of 274 metres (equivalent to about 900 feet), and secondly for a radius reduced from 274 metres; and he then compares the values given for various radii and a lemniscate transition curve with those for the same radii and a parabolic

curve. In the case both of altered and unaltered radii, the length from the tangent point to the end of the transition curve is 8 feet longer with the parabola than the lemniscate for a circle of 650 feet radius; but this difference decreases to $2\frac{1}{2}$ inches for 1,312 feet radius, to 0·31 inch for 1,968 feet radius, and to 0·08 inch for 2,624 feet radius, showing that for curves of small radius the difference between the lemniscate and the cubic parabola is considerable, and increases rapidly as the radius of the curve diminishes.

The Author next deals with the application of lemniscate curves to reconstructed lines, the only difference between these cases and the former ones being in the known constants. In all these cases the unknown quantity to be first found is the angle α contained between the tangent line produced and the chord of the transition curve; when this is known the calculation of the other values required is simple. The Author concludes with examples of the calculation of transition curves on a reconstructed line; first, for an unaltered radius of 250 metres (equivalent to 820 feet), and secondly for a radius reduced from 250 metres.

To the Paper are appended two Tables giving values of the angle α for curves with radii differing by a metre from 200 metres up to 800 metres (656 feet to 2,625 feet), the variation of α above the latter radius being negligible; the first Table is for curves with unaltered radius R, and is based on the formula $\sin 2\alpha = \frac{C}{3R^2}$; while the second Table applies to curves with radius reduced from the original radius R_o, and is based on the formula $\tan \alpha = \frac{C}{6R_o^2}(1 + 2\sin^2\alpha)^2$. A third Table follows giving the radius vectors of the lemniscate $r = \sqrt{3\,C \sin 2\theta}$, for sixteen values of θ between 0 and 3°. C in all these Tables is assumed = 12,000. There are six small diagrams in the text illustrating the expressions used in the calculations.

R. B. M.

The Influence of Water absorbed Hygroscopically upon the Strength of Timber.[1] By Julius Marchet.

(Mittheilungen des k. k. technologischen Gewerbe-Museums in Wien, 1896, p. 82.)

After the Author had concluded his former experiments, an opportunity occurred of testing some further specimens of the same woods from a different locality. The samples of hornbeam available were however not very well adapted for investigations with respect to transverse strength, because the growth was con-

---

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 472.

siderably contorted, and the wood was moreover, to begin with, extremely wet, which obviously affected the comparative results of the same when in a saturated condition. Four test-bars were prepared of each of the two varieties of hornbeam employed; the dimensions being uniformly 26·1 inches long and 1·3 inch square. Certain of these bars were tested in the dry state to ascertain their relative strength, and two of them were steeped in water, and their consequent gain in weight was ascertained from time to time. After these latter had been, owing to lack of time, only nine days in soak, these also were tested for strength. The bars experimented with in a comparatively dry state were found to contain from 22·5 to 31·4 per cent. of water (the percentage being calculated on the weight of the dry wood). These bars cannot, therefore, be regarded as properly air-dried, for in this case the moisture would not have exceeded 10 to 12 per cent. of the dry weight, while the bars placed in water, which contained from 33 to 48 per cent. of water, calculated in a similar way, were certainly not saturated, although the amount of water absorbed in the last twenty-four hours of the experiments was extremely trifling. In all cases the test-pieces had a clear bearing of 21·26 inches, and the weight was gradually applied at the centre. The results obtained are set forth in two tables illustrated by a graphic diagram, and the Author deduces from them the following conclusions.

1. These two varieties of hornbeam indicate a reduction of from 55 to 60 per cent. of the crushing strength when dry, if the wood is saturated with water, while the bending strength only shows a decrease of 10 per cent. in the same case.

2. The deflection of the wood is increased by the absorption of water.

3. The ultimate breaking stress very nearly coincides with the extreme range of elasticity, when the wood is saturated with water, and thus there is scarcely any condition of plastic flow (*Fliesszustand*).

4. The work exerted in bending (*Biegungsarbeit*) in the case of saturated wood is lower by about 60 per cent. than in the case of the wood in an air-dried condition.

In conclusion, the Author maintains that while the diminution of transverse strength and the crushing strength of timber in consequence of the absorption of water is an undoubted fact, it would be most useful if similar investigations could be carried out systematically with the commoner woods used in construction.

G. R. R.

Testing of Bricks and Tiles. By MAX CAREY.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1896, p. 63.)

This Paper contains an account of the methods of testing artificial stones and bricks, so that the general conduct of the experiments may be understood when the results of the experiments are published later.

In testing artificial as well as natural stones, individual results differ widely from the mean, so that reliable average values can only be obtained by having a large number of tests. For example: of ten bricks, numbered consecutively, and tested, the mean crushing load of the first five was 19·4 tons, and of the last five 18·03 tons; the mean of the ten being 18·71 tons.

The method of the estimation of the specific gravity, tenacity and absorption of water is described. Apparatus for studying the influence of heat and cold, for estimating the amount of soluble matter, and for testing the melting point of firebrick, is described.

A. S.

The Thermal Conductivity of Steel and Iron. By W. BEDLINGER.

(Verhandlungen des Vereins zur Beförderung des Gewerbfleisses, 1896, p. 33.)

Though during the last ten years a number of methods of determining the thermal conductivity of a material have been developed, the results for the same substance often differ widely. In order to determine whether the want of homogeneity of the material, or the different methods of experiments were responsible for the divergent results, and also to obtain definite values for the conductivity of iron and steel, the present investigation was undertaken. The method was developed by Prof. H. F. Weber in 1878, and rests on the following principle.

A cylinder possesses at all points the initial temperature u, then at a certain moment it is subjected to cooling such that its lower base is kept at the temperature 0°, while its other bounding surfaces are exposed in space of the same constant temperature 0°. The variation of the temperature at any point with the time can be calculated, the method being indicated in the Paper.

The temperatures were measured thermo-electrically. The method of experimenting is described in detail.

The observations and calculations for one experiment on a Bessemer steel cylinder are given in detail.

Fifty-two different specimens were experimented on; they are classed in three groups, wrought iron, steel, and cast steel; the results being given in tabular form.

Discussion of Results.—In the wrought-iron group, it seems that

the less the density the smaller the conductivity. A remarkable result is obtained from cylinders Nos. 1 and 4 made from the same material. No. 1 came direct from the ironworks; No. 4 was obtained through the ordinary trade channels. The values of the conductivity differed by 15 per cent.

In the steel group, the density varies from 7·84 to 7·92, the conductivity between 5·64 and 7·96. In three cases a cylinder of hardened steel had a conductivity less than that of the corresponding soft steel; viz., 4 per cent., 5 per cent., and 6 per cent. In one case, the hardened cylinder had 2½ per cent. greater conductivity.

In the cast-iron group, the density varies from 6·85 to 7·22, the conductivity between 5·59 and 9·19. The experiments show that the cylinders of this group had very little homogeneity.

The chemical analyses of the materials are not known, though it is questionable whether the analysis would throw much light on the differences of the thermal conductivity. It may be noticed that the extent of the variation of the conductivity is practically the same for wrought iron and steel as for cast iron.

These experiments show that different brands of iron may possess quite different conductivities. Other things being equal, the hardening of a steel reduces its thermal conductivity.

A. S.

The Influence of Cold on the Strength of Iron and Steel.

By Prof. M. Rudeloff.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1895, p. 199.)

This Paper contains an account of early investigations on the influence of cold on the strength of iron and steel, and an account of recent tests made in the Imperial Dockyard at Wilhelmshafen.

These later experiments were made on seven different materials, soft rivet iron, Siemens Martin steel, basic steel, wrought iron—the three latter materials being in the form of angles—spring steel, cast steel, and wrought iron in round bars one inch in diameter. Of each material nine test pieces were prepared for tension, bending, and hammering. The experiments were made at three different temperatures, 18° C., − 20° C., and − 80° C. The results of the tests are given in tabular form, and also a number of diagrams showing the alteration with temperature of the stresses at the elastic limit, at the yield point, and at the breaking point.

The experiments show that the stress at the yield point, and also the breaking stress, is raised by cooling below 0° C. The extension on fracture in general decreases on cooling; but the wrought-iron round bar is an exception; in this case the extension on breaking increases with cooling.

The influence of cold on the amount of flow at the yield point is

clearly shown; in each case this flow being greater at the lower temperatures. The spring steel and the cast steel show no decided flow at the yield point at ordinary temperatures, but at − 20° C. the flow is quite apparent, and at − 80° C. strongly marked. Similar phenomena are shown by the rolled wrought iron.

The results of the hammering tests show that at lower temperatures the materials investigated show greater resistance to alteration of form. The bending tests show that all the materials, except the rivet iron and the rolled wrought iron, are prejudicially affected by cold, the angle through which bending takes place without producing fracture being smaller the lower the temperature. The deterioration is most marked in cast steel and spring steel.

The Paper is accompanied by ten tables and fourteen figures in the text.

A. S.

Tests of Exploded Cylinders for Compressed Hydrogen Gas.

By Prof. A. Martens.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1896, p. 1.)

At the instance of the Royal Balloon Corps, tests of the materials of a number of iron cylinders for containing hydrogen gas were made; a number of cylinders having been destroyed by an explosion the cause of which has not been discovered.

A number of complete cylinders and of single pieces were selected by the Author for experiment. The selected pieces were immediately marked with the letters M, R and E, according to the group from which they were selected. There was selected from each group a cylinder which had been deformed but not broken by the explosion, broken pieces from the top and bottom ends of a cylinder, and a few broken pieces which appeared to have remarkable fractures.

The method of preparing the test-pieces, and their positions in the cylinders is described. Tension and bending tests were made, and some test-pieces drawn out under the hammer.

Chemical analyses were made by the Chemical Technical Institution. A microscopic examination was made, and a number of reproductions were made by means of the microphotographic apparatus.[1] The results of the tension and bending tests are given in tabular form.

From the analyses, the percentage of carbon in the materials R, M and E is 0·38, 0·26 and 0·17 respectively. The appearance of the specimens under the microscope is discussed.

---

[1] Mittheilungen aus den königl. techn. Versuchsanstalten, 1891, p. 278.

The tests show that the cylinders M have been made from a material which had not been mechanically worked at a low heat, since the tension tests on the material as received and on annealed specimens do not differ essentially. The elastic limit of the material as received is higher than that of the annealed specimens, but this may be due to the fact that the hydraulic tests produced a slight set, and therefore raised the elastic limit. The tests on specimens hardened in water show that the material can be hardened; the breaking stress rising from 41·1 to 53·4 tons per square inch. The extension on fracture with the hardened specimens was very small.

The experiments showed that the material of the cylinders R was fairly hard steel. The tenacity fell considerably on hardening in water, and it is feared that the material had been deteriorated during manufacture.

The cylinders E were made from wrought iron, which the chemical analysis shows was very pure. The material gains in strength by cooling in water, but loses the greater part of its ductility, though not to the same degree as the material M and R.

The Testing Institution recommend that during the manufacture of the cylinders they should be so marked that the inspector should be able to identify all cylinders produced from the same smelting. From each smelting, two test-pieces for bending and two test-pieces for drawing out under the hammer should be taken. Of every hundred complete cylinders, two should be submitted to a hydraulic test until a permanent increase of circumference lying between 0·5 millimetre and 1·5 millimetre is produced. The cylinders should be subjected to a water-pressure of 1·1 n, without suffering any permanent change of form; n being the pressure which, after filling under normal conditions, can be produced by exposing the cylinders to the sun. A number of details as to the preparation of the test-pieces is given.

To the question as to what specification the material should be made to, it is recommended that only the stresses on the yield-point and the extension and fracture should be specified, and that a premium should be placed on a high extension. A stress at the yield-point lying between 22 tons and 28 tons per square inch, and an extension of 10 per cent. might be accepted.

The question as to whether these cylinders might possibly have been injured by the hydraulic test is answered in the negative.

The Paper is accompanied by numerous Tables and forty-one illustrations.

A. S.

The Metal Spires of the Saïgon Cathedral. By ALBERT BUTIN.

(Le Génie Civil, May 2, 1896, p. 1.)

This is a description of the twin spires of the cathedral of Saïgon, which are entirely of metal; the octagonal framework, consisting of double angle-bar ribs tied together by six intermediate horizontal octagons of H-bar with radial connections from the centre to the ribs, and stiffened by angle-bar diagonals between these horizontal members. The upper ends of the eight ribs are connected into an eight-rayed casting, and above this are fastened to a large cross of cast-iron and wrought-iron angles with which each spire terminates. In four of the eight sides, gabled openings are formed, the gables being supported on cast-iron columns resting on the base of the spire. The base is secured to the masonry of the towers by means of brackets 7 feet 4½ inches deep on the inside of the walls, and tied together by a framework of H-bars which also carries a cast-iron chequered floor.

The spires are covered with stamped zinc bands, 2 feet 9½ inches wide, with a 4-inch lap, while the angles have zinc ridge plates, broken at intervals by ornamental crockets. These zinc plates are secured by copper clips, and insulated from the iron, to prevent electrolytic action, by a layer of pitch on red-lead paint. The height of the spires is 78 feet 9 inches from the top of the masonry to the base of the cross, which is 10 feet 2 inches high. The weight of the ironwork in each spire is 28½ tons, and that of the zinc covering about 2½ tons.

The description is accompanied by a full-page plate of details, as well as by four illustrations in the text, one of the latter being a photographic view of the work during erection.

R. B. M.

Framework with Initially Strained Members. By A. ZSCHETZSCHE.

(Der Civilingenieur, 1895, p. 425.)

A few forms of trussed beams under certain conditions of load have no stresses in the diagonals, an example being the "bowstring" girder under uniformly distributed load. In girders, the height of which varies with the maximum bending moment, it is usual to subject the diagonals to an initial strain, since it is found by experience that unstrained members, after a shorter or longer period of work, are pulled out of shape. The method of producing this initial strain was, in the majority of cases, very crude, and allowed of no means of regulation, or of determining the magnitude of the strain.

District-Engineer Ebert, of the Bavarian States Railway, has devised means of producing this initial stress, and measuring it to

a sufficient degree of accuracy. He had occasion to observe the Pauli Bridge, which had its diagonals considerably bent out of the middle plane, the consequence being that the passage of an express train subjected them to an impulsive load. If the elastic limit is exceeded a permanent set is produced, so that the condition of the structure gets gradually worse.

The prime cause of the gradual alteration of the diagonals in the Pauli Bridge was the faulty design of the junctions in the upper boom.

The straining of any diagonal was accomplished by placing a train on the bridge in such a position as to produce the greatest compression on the diagonal in question. Straining-tackle was then applied to bring the two ends closer together, and in this position the ends of the diagonal were fastened. On the removal of the load the diagonal would be subjected to tension.

The second portion of the Paper is devoted to a mathematical discussion of the stresses in framed structures with redundant members. An example of a girder with ten bays, the four middle bays being counterbraced, as used on the Mariort Bridge over the Danube, is worked out in full, the arithmetic being arranged in tabular form.

A. S.

Calculated and Observed Stresses on the Railway Bridge at Cosne.

By Messrs. Dupuy, Lethier and Guillot.

(Annales des Ponts et Chaussées, November, 1895, p. 461.)

This bridge carries a double line of railway over the Loire at Cosne, and consists of fourteen spans of 190 feet 2 inches each, the main girders being rectangular, with a single system of vertical and diagonal bracing in nine bays, the centre bay only being counterbraced. The main booms are trough-shaped and the verticals H in form, while the diagonals are pairs of flat bars united by two diaphragms equally spaced between the ends. All the joints are riveted. On loading the bridge, and measuring the extensions of the various members by means of a Manet apparatus, the results indicated stresses very unevenly distributed in the several members, and differing very widely from those obtained by calculation.

The Authors endeavour in this Paper to point out how these divergences between actual and calculated results can be accounted for, and the conclusions to be drawn therefrom.

The Manet apparatus (as improved by Rabut) consists of a rod, one end of which is fixed to a point on the member, the stress in which is to be noted, while the other end is in contact with the tail of a toothed arc gearing into a pinion moving a light pointer over a graduated dial, the pivot of the arc being fixed to the same

member sufficiently far from the first point to allow of an appreciable variation of length due to the stress. On considering the question carefully, it was found that when the bridge deflected under a load, the riveted joints tended to deform the diagonals and verticals from their original lines, thus lengthening one side while shortening the other, and affecting the uniform distribution of stress over the whole member; and the Authors analyse the effects of this bending on the stresses in the member. Only the verticals and diagonals are dealt with, and though the calculations, which are long and complicated, cannot but be approximate, the results obtained are fairly comparable with the actually observed extensions, and are most instructive.

The following conclusions are drawn:—

(i.) The usual methods of calculating stresses, due to moving loads, in bridge members do not take account of the stresses induced by the deformation of these members, and these indirect stresses may be even greater than the calculated ones.

(ii.) Faulty connections between the two sides of diagonals may appreciably increase the stresses, both in the diagonals and the verticals.

(iii.) The Manet apparatus works satisfactorily, but must be used intelligently, and fixed where the bending is a minimum.

(iv.) Notwithstanding the greatest care, it is impossible to entirely avoid this bending, or even to exactly calculate its effect. The stresses in the metal should therefore be kept well below the elastic limit.

(v.) Further similar investigations, on the lines of this Paper, from which some practical rules might be deduced, are much needed.

(vi.) To reduce the bending to a minimum, the following rules should be observed:—(*a*) The point of support to be in line with the neutral axis of the vertical. (*b*) All neutral axes of members meeting at a joint to converge to a point. (*c*) The resultant stress in any member to be, as far as possible, in the direction of its neutral axis. (*d*) Lattice construction to be preferred to double vertical-and-diagonal, and this to single vertical-and-diagonal systems. (*e*) The cross-girders not to have a span of more than 14 feet 9 inches in order to keep the deflection small. (*f*) The verticals to be very stiff. (*g*) The verticals to be secured to the flanges as well as to the webs of the main booms, and the webs to be sufficiently stout to resist horizontal shear. The Authors propose the formula: $e\,L = S$, e being the thickness of the web plate, L the depth of the boom over angles, and S the sectional areas of the diagonal.

(vii.) The Authors do not object to redundant members, believing that the several bars will each absorb their proper proportion of load.

The Paper is accompanied by twenty-six small illustrative cuts in the body of the text, and altogether extends to sixty-five pages.

R. B. M.

Railway Bridge over the Ruhr at Hohensyburg: its Damage by Flood in 1890 *and Restoration.* By — Breuer.

(Zeitschrift für Bauwesen, Berlin, 1895, p. 119.)

The floods which led to this catastrophe on the 24th of November 1890 were exceptionally high. On the Ruhr the water rose to within 2 feet 6 inches of the underside of the main girders of the bridge in question, and was 4 feet 3 inches higher than that of March 1888; at that time the highest experienced during the period of twenty-three years which the bridge had been erected. At five in the afternoon, immediately after the Berlin to Cologne express had passed, two spans, each comprising four main girders, gave way, the first pier from the left bank having overturned. Fortunately the attention of one of the railway employees was attracted by a straining and vibration of the permanent way in front of his cabin, and he was in time to warn a goods train and light engine approaching in each direction.

The Paper is illustrated by photo-lithographs, which show the damaged bridge, and again the structure after its temporary repairs. There are also two plates giving a general plan and elevation of the bridge with its foundations and various details, including the caisson used in the reconstruction of the pier overturned.

It is a double line bridge, each track being carried by a distinct floor and pair of lattice girders, with parabolic upper and horizontal lower booms. Its length from end to end of the ironwork is 459 feet 4 inches, there being four spans, each 103 feet 6 inches in the clear, and three piers, each 9 feet 9 inches broad and 54 feet long. The depth of the foundation of the pier which gave way was 33 feet 8 inches below the under side of the girders, and it was founded in the gravel. The main channel ran between the second and third pier, counting from the left bank, and these two piers, which remained uninjured, were carried down to a depth of about 35 feet 3 inches below the under side of the girders.

The following was the condition of affairs after the occurrence; counting from the left bank, the first pier had fallen on its left side towards the bank; of the two bridge-ways of the first span (each track being carried by a distinct superstructure), one remained hanging at its landward end on the abutment, the other end resting on the river bed, the other bridge-way of the same span had been carried a distance of 115 feet down stream. Both the superstructures of the second span were found at a distance of from 295 feet to 395 feet below the bridge, buckled and knit into one another in such a way as to be worthless, except as old iron. This affords an idea of the force of the flood, as each superstructure weighed 56 tons. Although the ironwork of these was worthless, that of the first span was repairable, being but little damaged. In both openings it was found that the river-bed had been scoured but to a depth of 16 feet below its former level, and this hole

extended for a distance of 20 yards above and the same distance below the bridge.

The fall of the pier is attributed principally to the peculiar situation of the bridge, viz., a short distance below the junction of the rivers Ruhr and Lenne, and the constricted waterway during flood at the site of the bridge. When the river is low the main stream runs parallel with the piers through the third and fourth opening, the other two spans being dry; but in flood the conjunction of the two swollen streams above the bridge site alters its direction, so that it impinges on the side instead of the end of the pier next the left bank, and at the same time a whirling motion is set up, tending to scoop out the river-bed, which is accentuated on reaching the pent-up stream at the bridge site.

In order to expedite the resumption of traffic, it was at first proposed to convert the two spans which had been destroyed into one, and to leave the fallen pier as it lay; thereby the difficulties of constructing a new pier on the site of that destroyed would be avoided, and at the same time an increase in the waterway would be gained. On consideration, however, it was found that it would be unadvisable to throw such an increased load upon the abutment and the second pier; also by restoring the fallen pier some of the ironwork could be utilized, and the symmetrical appearance of the bridge preserved.

It was consequently determined to restore it to its original form; but to carry down the foundations of the new pier to a greater depth and on to a firmer substratum.

At the end of November, the Dortmund Bridge Company commenced the work necessary for restoring traffic on one line of rails, by making use of the old girders and the erection of a temporary trestle pier. The line, with one track, was re-opened for passenger and goods traffic on the 1st of February, the trains being limited to a speed of 11 miles per hour. The length of bridge restored was 75 yards, and the time occupied sixty-nine days, during which time a severe frost prevailed; the work was continued at night by the light of electric and oil-vapour lamps.

The cost of this temporary work was £6,000, exclusive of the laying of the permanent way, points, crossings, &c., for taking the traffic from the double track to the single one across the bridge, which amounted to a further sum of £750. The regulations for working the traffic during this period are given.

For the reconstruction it was determined to carry down the foundations of the new pier to a greater depth than the former one, and to protect it against under-scour; to protect the left bank abutment by deep sunk sheet piling or a concrete apron; to increase the waterway section at the bridge by lowering the river-bed, and to carry out regulation works in the stream in the vicinity of the bridge.

An account is given of the reconstruction of the pier and its foundations by means of a wrought-iron braced and strutted caisson lowered from a staging, it being found that owing to the

wash-out there was not sufficient depth of ballast to hold piling, and that in addition, the construction of a cofferdam would occupy too much space in view of floods and ice. The caisson is similar in shape to the plan of the pier, 63 feet 4 inches long, 14 feet 5 inches broad, the pier constructed within it being 54 feet 1 inch long, and 10 feet 4 inches broad.

A great portion of the fallen pier lay in the way of the caisson, and this was broken up by a succession of charges of dynamite and the fragments removed, partly by a Priestman dredger and partly by divers. On the 31st of March, sufficient had been removed to permit of the sinking of the caisson, which occupied from the 16th of May to the 20th of August, and was effected with the aid of divers. Its lower edge was carried down to a depth of 37 feet 9 inches below the under side of the girders; a filling of concrete was put in, and the pier itself erected upon that. The bridge was completed and opened for traffic on the 14th of December, 1891.

The whole cost of the restoration, including the temporary works above described, amounted to £25,000.

D. G.

The Baaken Swing-Bridge in Hamburgh. By — Weyrich.

(Zeitschrift des Architekten- und Ingenieur-Vereins zu Hannover, 1895, p. 279.)

This swing-bridge carries two railway-tracks, a roadway, and footway across the entrance water-way known as the Magdeburg Haven leading from the Elbe and the Baaken Haven, or basin, to the Brookthor Haven, and by the Ericus Lock to the Ober Haven, &c. The Magdeburg Haven is tidal, the depth at low water is 18 feet 4 inches, and at high water 24 feet 3 inches; the average range of tide is therefore 5 feet 11 inches. The under side of the bridge-girders is 10 feet 6 inches above high water.

Previous to the erection of this structure mild steel (*Flusseisen*) had not been adopted in any instance for a railway bridge in Germany, but for this case it was considered to be peculiarly adapted, as it would effect, owing to its higher resistance, a saving of 25 per cent. of weight as compared with wrought iron, and thereby correspondingly diminish the cost of the hydraulic swing machinery. The steel used is that produced by the Thomas process.

The bridge crosses the water-way at an angle 59° 8′ 25″, and comprises four openings, the two centre ones being spanned by the two equal arms of the swing-bridge.

The whole length of the structure is 290 feet 6 inches, of which 175 feet 6 inches pertains to the swing spans. The clear openings of the latter are each 70 feet measured along the axis of the bridge, and the two fixed side spans are each 45 feet 8 inches, measured in the same manner.

Owing to the considerable width of the bridge, viz., 44 feet 4 inches, and to lessen the depth of the cross-girders, it was decided

to construct it with a third main longitudinal girder, which girder was also intended to shut off the railway traffic from the road and footway. Consequently, as the single rail track portion would occupy less room than the road and footway portion, the centre girder does not, so to speak, fall midway between the two outside ones. During construction, however, it was found desirable to put down a second track of rails, and this had to be laid along one side of the roadway. Out of the breadth of 44 feet 4 inches, 14 feet 9 inches is devoted to one track of the railway, 19 feet 8 inches to the roadway, and 8 feet 3 inches to the footway. For the roadway timber planks and paving are used, and for the footway timber longitudinals and planking. The girders of the swing-span are of the lattice type, with parabolic upper and horizontal lower booms, divided into twenty bays. The girders of the fixed spans are parallel-boomed lattice-girders. The main cross-girder over the pivot of the swing-spans girder is formed of a fish-bellied box-plate girder, with three webs. All the rivets are of wrought iron. The depth of the swing-spans girders (175 feet 6 inches long) is about 20 feet 4 inches at the centre, and about 7 feet 11 inches at the ends, which latter is also about the depth of the fixed-spans girders. The main cross girder over the pivot of the swing-span is about 5 feet 1 inch deep.

The arrangement of the machinery for applying the hydraulic power in swinging the bridge is described in detail. In effecting this, to begin with, the pivot, which at its lower end fits into and is free to turn in the bed-socket, is lifted by the hydraulic pressure a height of 6 inches, and the bridge supported entirely upon this pivot, is, as it were, afloat. The pivot above where it clears the bed-socket gradually enlarges, and at its crown, immediately below the main cross-girder, which is attached to its head, in rotating is kept in position by four guide rollers affixed to a circular curb built in the masonry. In this way the pier carrying the swing-bridge is only of such a width as is necessary for a foundation, there being no roller path required. The pipes conveying the hydraulic pressure to the swing-gear are so laid as to be readily accessible for inspection. The arrangements are such that the maximum hydraulic pressure is limited to 442 lbs. per square inch, the working pressure being 427 lbs. per square inch. The opening and closing of the bridge occupies three minutes. The weight of the structure to be lifted is 440⅓ tons, the area of the pivot-base is 2,480 square inches, the diameter of the base being 56⅓ inches.

The machinery and arrangements for swinging the bridge are partly housed on the western abutment and partly on the swing-pier.

Particulars are given of the construction of the two abutments and the three piers. The foundation-ground varied from clay above to sand and gravel below. The abutments, &c., are of concrete faced with masonry in the upper portion, and rest on a pile foundation. The details of the machinery and construction are fully described and illustrated by diagrams, and the calculations,

tests of metal, results of experimental loading, &c., are given. The cost was as follows:—

	£
Excavation, &c.	150
Masonry, concrete and foundations	11,200
Machinery house	750
Steel superstructure	5,750
Swing machinery	3,100
Timber roadway	950
Painting	200
Lighting arrangements	150
Dolphins	200
Design and superintendence	1,250
	£23,700

D. G.

Renewal of the Manoir Bridge over the Seine. By — Le Bris.

(Revue générale des Chemins de fer, December, 1895, p. 265.)

This bridge is one of five in course of renewal carrying the Western Railway of France over the Seine, between Paris and Rouen, and is 687 feet in length. In order not to interfere with the traffic, the new bridge was built at a distance of 66 feet from the old bridge. The two main girders are lattice, continuous over three spans, with cross girders and rail-bearers.

The bridge was erected on a platform on the Rouen side of the river, in the axis of its permanent position, and was moved forward by launching. Great care had to be exercised to keep the rollers at a constant level, in order that the forces exerted during the launching should not exceed those found by calculation, and four double rows of masonry pillars were therefore erected to support them. The length of platform obtained only allowed a portion of the bridge to be erected at one time. The greatest space which the superstructure had to be launched over was 233·60 feet, and on account of this overhang, the front portion was lightened as much as possible to avoid an excessive strain in the metal. With this object in view also a special head-piece, 95·15 feet in length, was attached to the permanent structure, and weighed 65 tons, acting at a distance of 45·93 feet from its junction with the girder. In order to stiffen the main girders during launching, the first six panels were strengthened with temporary gussets. When about half of the bridge had been erected with the head-piece, the launching was proceeded with in proportion to the progress of erection at the rear; there were altogether eight launches before the bridge was in its final position. The launching was effected by means of two winches; hemp cables, $2\frac{3}{8}$ inches in diameter, were specially manufactured to take the place of chains. One of the winches was fixed on a bracket against the abutment, and the other on the flooring of the bridge. The speed obtained was 33 feet an hour for the first launches, and 24·61 feet for the later

ones, when the whole weight of the bridge was rolled. A description is given of the sets of rollers used. The total weight of the bridge is 1,985·59 tons, or 8·07 tons per lineal yard. The total cost of the ironwork was £39,497 including erection.

A description is also given of the masonry and foundations, and the Author enters in great detail into the strains both for the permanent position and those exerted during the progress of the launching and gives numerous diagrams. The bridge was opened for traffic in April, 1893.

Nine plates accompany the Paper.

J. A. T.

A Bridge Wreck on an Electric Railroad.

(The Railroad Gazette, New York, January 24, 1896, p. 52.)

The bridge, which fell on the 9th of January under a motor car of 16,000 lbs. and a coal-truck of 50,000 lbs. weight, is situated on the standard gauge Akron, Bedford, and Cleveland Electric Railway at Bedford, Ohio, and was erected in October, 1895. The fallen portion was a Pratt truss of 140 feet length and 28 feet depth, with five panels, each being sub-divided into two of 14 feet length. This truss was preceded by ten and followed by five trestles of 14 feet span, each alternate panel being braced so as to form a tower. The track, 40 feet above the stream, had a gradient of about 6 per cent., and the train, with three attendants, had come down, with brakes set on, to stop on the horizontal 140 feet span near the power-house.

The truss, although in the usual upright position, was used as a deck-bridge, posts being erected for the support of the platform. These posts consisted of two L bars—4 inches by 3 inches by $\frac{5}{16}$ inch—strengthened later by a plate 8 inches by $\frac{1}{2}$ inch; the raking strut was composed of two 7-inch ⊔ bars with a $\frac{3}{16}$-inch web and a plate 14 inches by $\frac{1}{4}$ inch. The lower half of the first diagonal tie was composed of two L bars, 3 inches by 2 inches by $\frac{1}{4}$ inch, for a calculated stress of 50,990 lbs. This member was broken, and the fracture showed an old break in one of the bars, so that, judging by the position of the train in the wreck, the stress per square inch may have been 56,000 lbs. Two attendants were killed. The Wrought Iron Bridge Company of Canton, Ohio, have proposed to rebuild the structure free of cost to the Railway Company.

M. A. E.

Hydraulic Suction-Dredge for the Navigation Improvements of the Mississippi River.

(Engineering News, New York, April 23, 1896, p. 277.)

The dredge was designed for clearing away sand-bars in the Mississippi, and the contract price was £34,555. The principle of the design, which is suction through the centre of revolving cutters, has already been successfully applied in dredges for Pacific coast harbours, and elsewhere. At the front end of the dredge is a battery of six revolving cutters with vertical axes attached to floating ladders, and operated in two sets of three cutters each. The suction pipes from each set of cutter combine near the front of the vessel to form a single suction-pump, leading to a centrifugal pump. There are therefore two centrifugal pumps. At the rear of the pumps are the discharge pipes, which extend to 1,000 feet astern of the dredger, where they discharge.

The length of the vessel between perpendiculars is 172 feet, and the beam 40 feet. The displacement is 1,200 tons, made up of 310 tons of hull, 800 tons of machinery, and 90 tons of fuel.

The suction-pipes are 19½ inches in diameter, and on the end of each is a revolving cylindrical cutter 5 feet in diameter. Each suction-pipe is contained in a watertight pontoon, three on each side, and braced together to form a rigid structure. Each set of three pontoons can be swung up and down by means of a derrick in the bow of the vessel. The cutters are driven by a compound engine, placed in the bow of the dredge, by means of bevel-gearing. The cylinders are 14½ inches and 29 inches, and the stroke 18 inches. The cutters make 25 revolutions per minute. The derricks for raising and lowering the cutters are worked by means of a double-cylinder engine, 12½ inches in diameter, and 15 inches stroke. The main pumping engines are amidships. They are triple-expansion, vertical inverted condensing four cylinder engines of tandem type, each set driving one centrifugal pump. The cylinders are 20½, 33, 38, and 38 inches diameter respectively, and have a stroke of 24 inches. They run at 175 revolutions per minute. The impellers are 7 feet in diameter, the suction-pipe 33¾ inches, and the discharge 33 inches. There are four water-tube boilers of the Heine type. The river water, which is used in the boilers, is carefully filtered. At the stern are two large timber uprights, which can be raised or lowered by an independent engine. When the dredge is in operation these are lowered into the river-bottom and serve to hold the vessel in place, or as pivots on which to swing it. There is also an arrangement by means of which the vessel can be pushed forward against the sand-bar which is to be cut away. Each of the steel discharge-pipes, which are 1,000 feet long, is floated on the water by means of twelve steel pontoons, connected together by coupling-bars. The lengths of pipe are connected with rubber hoses. The vessel is fitted with

an electric light plant comprising, in addition to the glow-lamps for internal lighting, two search lights. The crew consists of seventeen men. It is proposed to improve the method of manipulation of the dredge by attaching a pair of stern-wheel steamers, one on each side, and to place a propeller on each bow of the dredge, driven by means of electric motors; and it is expected that in this way it will be possible to keep the cutters pressed up to their work, and to control their lateral movement. As much as 7,798 cubic yards have been discharged per hour through 1,040 feet length of pipe, of which 36·4 per cent. consisted of solid matter. The forward speed of advance was 5 feet per minute, and 3 cubic yards of sand were dealt with per I.HP.

S. W. B.

The Ports of Trieste and Fiume in 1895. By Nádory Nándor.

(Zeitschrift des österreichischen Ingenieur und Architekten Vereines, 1896, p. 65.)

In this article the Author, formerly superintendent of the harbour-works at Fiume, comments upon the remarks of Mr. Bömches,[1] giving statistics in reference to the concrete composition, and testing, and the progress of the work, and discussing the causes of the subsidence of portion of the breakwater. He does not consider that any cavities existed in the bed, but that the superincumbent weight simply displaced the upper stratum of soft soil and sank down to the solid bed. The Paper is illustrated by several sections of the breakwater.

P. W. B.

The Harbour of Harburg.

(Zeitschrift für Bauwesen, Berlin, 1895, p. 107.)

The town of Harburg lies about 6 miles south of Hamburg, and is situated on the left bank of the stream known as the South Elbe, which branches off from the main Elbe about 9 miles above Hamburg, and rejoins it again about 6 miles below that city, the intervening island thus formed being known as Wilhelmsburg.

A history of the locality from the 9th century is given. In 1649 the fortress lying between Harburg and the river was erected, the horse-shoe shaped canal around the fortress being used as a harbour with communication to the South Elbe at each end. From the southern side of the horse-shoe canal led off a narrow channel to the Market-house (Kaufhaus), now a factory, and a canal, or mill lead, cut in the 16th century, $4\frac{2}{3}$ miles long,

---

[1] Minutes of Proceedings Inst. C.E., vol. cxxiv. p. 458.

brings down water from the Seeve, a small upland tributary of the Elbe.

Harburg is connected with Hamburg by the Venlo-Hamburg Railway, opened in 1873, the amount of shipping having been at that time greatly reduced in consequence.

As regards road communication between Hamburg and Harburg, the railway bridge over the main or Northern Elbe carries also a roadway, but the Southern Elbe is crossed by a ferry. Mention is made of Napoleon, in 1813, having bridged both the north and south Elbe in a space of three months, 10,000 workmen being employed. In 1817 the whole structure was removed.

Various Tables are given, including the steamboat traffic between Hamburg and Harburg, for the period 1872 to 1892; also the increase in population of Harburg for various years, commencing with 1823, when it was 3,829, and ending in 1893, when it was over 40,000. The Paper is illustrated by four plans, viz., by a general plan, scale 1:150,000, including Hamburg, Harburg and the surrounding district; a plan, scale 1:4,000, of the citadel and harbour in 1848; a plan, scale 1:6,250, showing the town of Harburg, the harbour, citadel and the South Elbe in 1856; and, lastly, a plan to the same scale, and including the same area as that last mentioned, but showing the conditions in 1894. In this a great change is noticeable, the citadel has disappeared and its site is occupied by wharves, ship-building yards, petroleum stores, &c.; additional basins have been provided, one of the locks (the eastern) has been reconstructed, and is now the larger of the two, the railway from Hamburg made, and opened in 1873, as also the Lower Elbe Railway in 1881. The terminal station of the Harburg branch of the Hannover Lehrte and Braunschweig Railway, opened in 1847, has been greatly altered in the period referred to.

The present harbour arrangements comprise the following, viz.:—

	Acres.
1. The Petroleum Basin	9·27
2. The channel leading from the Western Lock to the Main Basin (Verkehr's Hafen), the Binnengraft Basin and the Lothse Basin (Canal)	13·31
3. The Main Basin (Verkehr's Hafen)	18·90
4. The Timber Basin	3·46
5. The Ziegelwiesen Basin	4·74
6. The Kaufhaus	1·98
7. The Western Canal	2·22
8. The Eastern "	3·33
9. The Hafen "	5·14
Total acres	62·38

In the Hafen Canal there is a depth of 16 feet 4 inches; in the Eastern Canal, 14 feet 9 inches; in the Western Canal, 12 feet 9 inches; in the Kaufhaus Canal, 8 feet 10 inches; and in the Lothse Basin and the Ziegelwiesen Basin, 19 feet 8 inches.

The reconstructed eastern lock has four pairs of pontoon gates,

and has a chamber of 55 feet 9 inches broad and 229 feet 8 inches long in the clear; the sill is 17 feet 4 inches below mean water-level. The outer approach from the river to the new lock is 656 feet long and 164 feet in breadth, the bottom being 18 feet below mean river-level. The old, or western lock is 32 feet 7 inches wide and 143 feet 9 inches long in the clear, the depth varying from 10 feet 10 inches to 14 feet 5 inches.

The road traffic is conveyed across the Southern Elbe by ferry, by steamers and smaller vessels. In the year 1892 the steamer made 22,349 trips, conveying 101,439 passengers, 41,166 vehicles, and 3,898 horses, oxen, &c. The average cost of working per annum is £1,450. Full details of the working are given, and a list of the dredgers, ferry-boats, ice-breakers, &c.; also the tonnage of river and sea incoming and outgoing vessels between 1849 and 1892.

The cost of the various works of the Harburg Harbour carried out between 1846 and 1893 are given, amounting to a total of about £243,550, of which £102,902 was for the new lock, and £912 for the pontoons of same, and the cost of dredging and maintenance during the same period was about £36,935.

Particulars of the tides on the South Elbe are given and of the regulation works referring to it, and to its minor branch channels, including the Reechersteig, Kohlbrand, &c., in the period 1869 to 1893, the amount expended for this being £279,250.

D. G.

New Harbour Works in Finland. By M. Strukel.

(Allgemeine Bauzeitung, Vienna, 1895, p. 20.)

In the construction of the quays, moles, landing-stages, &c., of these harbours timber is very largely used on account of its abundance, and the fact that, owing to the low temperature of the water, it is free from the attack of the sea-worm (*Teredo navalis*). The works are generally formed of cribwork (timber framings filled with stone or concrete), especially for the foundations and lower portions, and from their widespread use the Finns are especially expert in their construction.

The harbour of Hangö lies at the outer end of a narrow promontory stretching for about 20 miles southwards from the south-west coast, and forms at Hangöudd the southernmost point of Finland. This harbour, being the only one open as a rule throughout the winter, is consequently of considerable importance to the whole of Finland. The original harbour was constructed in 1872–73, and worked in conjunction with the Hangö Hyvinge Railway by private enterprise, but the development of trade was slow until 1878, when lines of steamers were started for winter

service between it and Stockholm, also to Copenhagen and England, when trade rapidly increased, and the works for the enlargement of the harbour, described in the Paper, had to be carried out in 1890.

The coast here being only partially shut off from the force of the sea by outlying islands, protective works were necessary. The rocky headland of Drottningberget separates the Western from the Eastern Harbour, the former being the more important, owing to the greater depth of water and more direct connection with the main line of the railway.

For protecting the Western Harbour, a mole of 467 feet long (measured along its southern face) was built to serve as a breakwater and as a landing-stage. The mole below water is formed by cribwork in 118 feet lengths, sunk on the natural bed of the sea, and after being carefully filled in with stone, the upper quay wall constructed thereon in granite masonry. The interior space or hearting of the mole was below water filled with stone, and above water-level with earth and sand. On this three lines of rail were laid, and on the inner side of the quay a timber landing-stage of 23 feet 8 inches broad. The adding a length of 292 feet to this mole was commenced in 1889 and completed in 1891, and the works included the dredging out of the harbour to a minimum depth of 19 feet 8 inches for a width of 460 feet. The details of construction, carrying out of the works and cost, are given.

Up to the year 1889 the depth of water and length of quays in the Helsingfors harbours were as follows: For large vessels with draughts from 10 feet to 17 feet 6 inches in the Southern Harbour, a quayage length of 1,223 feet, in Sandviks Harbour 87 feet, and in Sörnäs Harbour 1,107 feet. For smaller vessels, with draughts of 6 feet to 10 feet, in Southern Harbour a quayage length of 1,470 feet, in Sandviks Harbour 315 feet, in Sörnäs Harbour 571 feet, in Northern Harbour 295 feet, and in Brobergs Harbour 758 feet, or a total quayage length of 2,408 feet for large vessels, and 3,410 feet for small vessels.

To meet the demands of the increasing trade it was determined to construct in the Southern Harbour new quays having a water depth of 19 feet 8 inches to 21 feet 4 inches, and to erect warehouses and cranes, of which there was great need; also to put this harbour into connection with the Helsingfors railway system, which had been previously delayed, owing to the considerable difficulties in construction and large outlay. The details of the works determined upon were:—

(1) In the Southern Harbour the former narrow quay to be replaced for a length of 1,378 feet by a quay with 16 feet 6 inches to 21 feet 4 inches depth of water, and thereby obtain a quay length of 1,969 feet.

(2) On the eastern side (Skattudden) of this harbour, not hitherto used for shipping, to construct a quay 1,509 feet in length, and erect thereon warehouses, railway sidings, &c.

(3) On the northern side of this harbour to convert the there

existing quay in shallow water into a quay of 508 feet in length, with water-depth sufficient for small steamers up to 10 feet draught.

(4) To construct the so-called Harbour Railway so as to put the quays of the Southern Harbour into connection with the town station; also to make a railway connection with the Sandviks Harbour.

(5) New quays to be constructed in the Sörnäs Harbour, with increased water-depth.

(6) Various warehouses to be erected.

Formerly a considerable portion of the magazine quay in the Southern Harbour was used as a timber harbour, and to obtain room for the new quays for large vessels it was considered advisable to remove this traffic to the Northern Harbour, and in view of the insufficient depth of water existing at the latter place to carry out a large T-mole. This was executed in 1890–91, and the new quays on the western side of the Southern Harbour commenced, and since continually proceeded with.

The dry-dock, which forms part of the old harbour arrangement, is the only one in the country and the largest in the north. It lies at the Sandviks Harbour, and has a sole length of 300 feet, and breadth of 60 feet, a depth of 27 feet 10 inches, an outlet width of 55 feet 9 inches, and a water depth over sill of 18 feet 4 inches. The dock was blasted out of the solid granite rock, with a small addition of masonry-walling at one side.

The Paper is illustrated by numerous diagrams.

D. G.

Protection of the Shore of the Island of Baltrum.

By — Schelten and — Roloff.

(Zeitschrift für Bauwesen, Berlin, 1895, p. 387.)

A general description is given of the East Frisian Islands, of which Baltrum is the smallest. From a geological standpoint it would appear probable that at a comparatively recent period the present North Sea Coast Islands, extending from the north-west point of Holland to Jutland, were then part of the mainland, and formed an unbroken chain of sandhills fringing the shore, except where interrupted by the outfall of the Rivers Ems, Weser, and Elbe. The set of the flood-tides and the prevailing westerly winds have caused the sea at different times to break through this fringe at various points, and gradually convert it into a series of islands, and this combined action at the present time tends to cause a constant travel of each island to the eastwards. The island in question lies close to the coast, rather west of midway between the mouths of the Ems and of the Weser, the island next east of it being Norderney.

In this instance the ebb-tide, passing out through the strait Wichter-Ee (now about ⅝ mile wide, but which in 1861 was less than ¼ mile broad), separating the western end of Baltrum from the eastern end of the island of Norderney, has an eastern set causing it to impinge upon the western extremity of Baltrum. This is attributed to the area and volume of water contributing the ebb, lying between the island of Norderney and the mainland (on the east), being greater than that between Baltrum and the mainland (on the west), the tendency being to deepen the channel and scour away the foreshore at the western end of Baltrum.

A series of comparative plans, accompanying the Paper, with soundings thereon showing the condition of the western promontory of the island in 1872, 1875, 1878, 1881, 1885, and 1891, and a general view of the island in 1891 is given. The latter shows the high-water and low-water line in plan for 1860 as compared with the condition of matters in 1891. The difference between high and low water of ordinary tides is 7 feet 8 inches. Cross-sections of the Wichter-Ee strait are also given, taken in 1876, 1881, 1885, and 1891. At low water, spring tides, the length of the island, west to east, is about 3 miles, and from north to south rather less than 2 miles; at high water of extraordinary spring tides, however, there remains only an area of about ⅜ square mile uncovered. There are two villages, Westdorf and Ostdorf, with together thirty-nine dwelling-houses and 156 inhabitants, mostly fishermen.

Protection works for the western point of this island were commenced in 1860, but the first groyne was constructed in 1873, and gradually increased in number, there being fourteen shown on the plan of 1891.

A detailed account of the construction of these groynes, together with sectional diagrams, are given, and of the longitudinal works protecting the foot of the sand-dunes. The works comprise rows of piling, with intervening stone pitching on a concrete foundation-bed, and an account is given of the most severe storms occurring during the period of 1873 to 1891, and the consequent damage and repairs.

The total length of groynes constructed in this period was 2,951 yards, and the length of dune protection works 1,945 yards.

	£
Cost of the works from 1873 to 1890 . .	90,640
Maintenance of ditto	13,925
Total . . .	£104,565

D. G.

The Construction of the Beacon-Tower of Trois-Pierres.

By G. Mallat.

(Annales des Ponts et Chaussées, October, 1895, p. 365.)

This tower is situated near the entrance to the port of Lorient and its construction was attended with serious difficulties, on account of both its exposed situation and its foundation on rock 6 feet 6 inches below low-water level of equinoctial spring tides. The Author first gives the reasons for the erection of this beacon, among them being the grounding near here of the French ironclad "Devastation" in 1881.

The base of the tower was formed of three superimposed concrete cylinders, the lowest being 30 feet 10 inches in diameter, with a mean height of 4 feet 5 inches; the second 27 feet 3 inches in diameter, and 3 feet 7 inches high; and the upper one 23 feet 7 inches in diameter, and 3 feet 10 inches high, giving the base a total mean height of 11 feet 10 inches above sea-bottom. In order to clear the rock, the seaweed covering it was first hacked off by divers, the roots were then destroyed by hydrochloric acid, and the rock was then scrubbed, first with steel scrapers, then with wire brushes, and lastly by bristle brushes. A mast was then fixed to mark the centre of the structure, and supported by bags of concrete. The outer wall of the base was formed with bags of concrete, placed radially, and laid by hand by divers. To facilitate the exact location of these bags, each diver was attached to the centre mast by a light pole fastened to his waist, of such a length that, when standing back to the mast, his chest was against the inside of the wall of sacks. The concrete was mixed and filled into the sacks on a barge anchored close to the site, and by means of a crane each sack was lowered to the divers in an iron box. The divers guided the box to the required position, the movable bottom was released, and the sack thus deposited exactly where wanted. When the outer wall of each tier was completed, the interior space was filled with a similar concrete. This was lowered in boxes, which were opened in much the same way by the divers, allowing the concrete to fall out gently, without much disturbance of the water. The sacks, of a stout but loosely-woven material, when empty measured 5 feet 3 inches by 3 feet 11 inches, but when filled they were only 3 feet 3 inches long, and contained rather more than $\frac{1}{9}$ cubic yard. The concrete was formed of 843 lbs. of Portland cement to 1 cubic yard of gravel, no stone being used, as experiments tended to show that this weakened the concrete. The work was carried out by means of a barge, on which were the materials for the concrete, a large and a small boat, and a tug, the latter for conveying the barge and boats to and from the site, and having on it the pumps for the divers. Owing to unfavourable weather the execution of this part of the work was spread over three summers, but beyond the

displacement of the mast on one occasion, no damage was done in the intervals.

The tower itself was octagonal, and of the same composition as the base, but as this portion was executed at low-water and in the dry, blocks of stone were buried in the concrete. It commences at a level of 5 feet 3 inches above low-water of equinoctial spring tides, with a diameter of 16 feet 5 inches, and tapers to a diameter of 13 feet 5 inches at its top, which is 29 feet 6 inches higher. The focal plane of the lamp is 39 feet 9 inches above low-water of equinoctial springs, and the lantern is 5 feet 3 inches in diameter. The tower is solid, and the concrete was filled in between shutters supported by cast-iron ribs at the angles of the tower, the ribs being bolted together in short pieces 1 foot 5 inches long, equivalent to two shutter boards, and the shutters firmly wedged in. The construction of the tower occupied from July to October of 1894, though work was only possible on thirty-five days.

The base of the tower cost on an average 51*s.* 4*d.* per cubic yard, and the octagonal portion 57*s.* 3*d.* per cubic yard, the extra cost of the upper portion being due to the necessity of tide work, of which the under-water portion was independent. The total cost of the tower, exclusive of the lantern, amounted to £1,192 1*s.* 8*d.*, which sum does not include £142 16*s.* 0*d.*, the cost of the shuttering, which can be used again.

At the present time the sacks forming the outside of the base are well united and are covered with a quantity of small shells, which protect the work from the action of the waves. The structure has up to now sustained no damage of any kind.

The Paper is accompanied by a chart of the approaches to Lorient, a plan of the site of the beacon, details of the construction, and a sketch showing the work in progress.

R. B. M.

Flow of Water in 48-inch Pipes.

By Desmond Fitzgerald, M. Am. Soc. C.E.

(Proceedings of the American Society of Civil Engineers, January, 1896, p. 1.)

These experiments were made in 1894 and 1895 on the Rosemary siphon, which constitutes part of the Sudbury aqueduct supplying the city of Boston with water. The pipes had been in use sixteen years; additional interest was attached to the experiments because Mr. F. P. Stearns, M. Am. Soc. C.E.,[1] investigated the discharge of these pipes when new.

The Sudbury aqueduct is 17·4 miles long, the greater portion of it having a section 9 feet wide and 7 feet 8 inches high. At a distance of 11·7 miles from its head the water is carried across the

[1] Transactions of the American Society of Civil Engineers, vol. xiv. p. 1.

valley of the Rosemary brook through two 48-inch cast-iron pipes, 1,800 feet long, forming an inverted siphon which descends 50 feet below the ends. The pipes were laid in 1877 and brought into use in 1878. They are socket and spigot pipes, cast in 12-foot lengths, and coated with Dr. Angus Smith's coal-tar preparation. The losses of head were measured by piezometer tubes screwed into the sides of the pipes near to the two ends of the siphon, their distances apart being accurately measured.

It was found impossible to arrange a weir in the aqueduct, near to the siphon, that would admit of a greater velocity than 3·7 feet per second through one pipe. The flow through each pipe up to this velocity was measured in turn, then the tubercles were scraped off one pipe and further experiments made with the cleaned pipe. To continue the experiments at a higher velocity the above weir was removed and two weirs were erected at the terminal chamber of the aqueduct 5·3 miles distant. By this means velocities up to 7·25 feet per second were obtained in the cleaned pipes, and velocities up to 5·5 feet per second in the tubercled pipes.

The levels of the water over the weirs were read by means of hook-gauges, with the zeros carefully adjusted to the level of the lips of the weirs, and their discharges were reduced in accordance with Bazin's experiments.

To compare these experiments with those made by Mr. F. P. Stearns in 1880 the following Table was prepared:—

Velocity.	Stearns's Value for c for New Pipes.	Fitzgerald's Value for c for Cleaned Pipes.
3·74	70·1	70·0
4·96	71·0	70·9
6·19	72·0	71·6

In the Chézy formula, $v = c\sqrt{d\,i}$, where v is the velocity in feet per second, d the diameter in feet, and i the virtual gradient, for the tubercled pipe the experiments gave $c = 55\cdot2$, but for the cleaned pipe c varied with the velocity and was expressed by the formula $c = 65\cdot9\ v^{0\cdot045}$.

The following formulas were found to best fit the experiments, and were arrived at by the method of logarithmic homologues:—

For cleaned pipes $v = 85\cdot6\ d^{\frac{1}{2}}\ i^{\frac{1}{1\cdot9}}$

For tubercled pipes $v = 55\cdot2\ d^{\frac{1}{2}}\ i^{\frac{1}{2}}$.

A. W. B.

Failure of the Bouzey Dam.

(Report of a Special Commission of the Ponts et Chaussées.[1])

The Report commences with a short résumé of the recognized methods of calculating the pressures in masonry dams:—

(1) Mr. Delocre assumes in his calculations, taking a unit length of the dam, that, in any horizontal section, the thrust due to the horizontal pressure of the water above that level is counteracted by the friction and cohesion of the mortar in that plane, and that the section has to support a vertical pressure equal to the weight of the portion of the dam above that level applied at the point where the resultant of that weight and the water-pressure intersects the plane. The intensities of the pressures are calculated on the assumption that the stress varies uniformly across the section. The profiles of the Furens dam (164 feet high) were calculated according to this method, the maximum vertical pressure being limited to 5·9 tons per square foot; likewise those of the Ban dam (148 feet high), but in this case the limiting pressure was increased to 7·3 tons per square foot. In the Tournay dam (116 feet high) the limit was taken as 6·4 tons per square foot.

(2) After the completion of the last-mentioned dam it was decided to raise it 3·3 feet, and Mr. Bouvier, in recalculating the stresses, introduced a modification into the method adopted by Mr. Delocre, by which the maximum pressures arrived at by the first system are divided by the cosine squared of the angle which the resultant makes with the vertical, to get the true maximum. This gave the maximum pressure in the Tournay dam as 8·5 tons per square foot, instead of 6·4 tons per square foot by the first method; and he concluded that, taking account of this correction, a dam built of good hydraulic lime might be subjected to a maximum pressure of 9·0 tons per square foot after two or three years, and 12·8 tons per square foot after ten years.

(3) Mr. Guillemain, while adhering to Mr. Bouvier's method, advocates that the pressure should be calculated on all planes passing through the point sustaining the maximum pressure, so as to arrive at the actual maximum pressure in a dam.

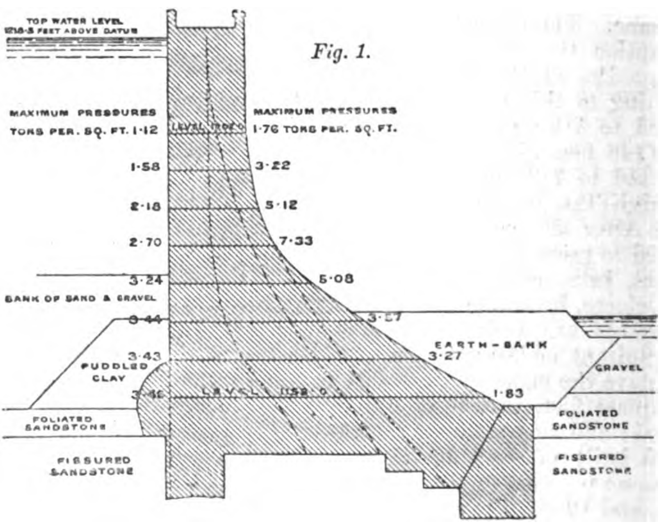
The effect of a dam being waterlogged below a certain level for a given distance from the face is next considered, and is shown to be, to decrease the amount of the resultant, but to move its point of application nearer to the outside face.

The Fig. shows the section adopted for the dam in dotted lines; it was approved of by the Council of the Ponts et Chaussées on the understanding that the dam should not be raised at once to its full height, but that the level of the water should be kept provisionally at 1,212·0 feet above datum, and not be raised to its ultimate level, 1,218·5 feet, until the dam had thoroughly con-

[1] The original is in the Library Inst. C.E.

solidated. The lowest draw-off level was fixed at 1,169·3 feet. The dam was straight, and its length was 1,700 feet; the contents of the reservoir at the provisional level being 1,034 million gallons, and at the final level 1,540 million gallons. The dam was built on the new red sandstone, which was fissured and permeable, and to prevent the water getting underneath the dam a guard wall was carried down beneath the water-face into the solid rock. The masonry was built with hydraulic lime mortar, and the inner face coated with plaster of cement mortar 1½ inch thick.

The guard wall was built in 1878 and 1879, and in its construction springs were met with that were with difficulty sealed. The dam itself was built up to the level of 1,187 feet for a length of



Bouzey Dam, amended Section.

Scale $\frac{1}{400}$.

Section first adopted . . . . - - - - - - - - -
Lines of resultant pressures for amended section, reservoir empty and full — · — · —

820 feet in 1879 and completed in 1880. During its construction the engineers, on representing to the Minister of Public Works the greatly increased storage that would be obtained at a small additional cost by at once raising its height to the ultimate level, obtained permission to do so.

The filling of the reservoir was started in November, 1881, about a year after the completion of the masonry, with the water of the River Avières. When the water in the reservoir attained the level of 1,187 feet, springs appeared on the lower side of the dam, having a flow of about 2 cubic feet per second. In December, 1882, two fissures, at distances of 243 yards and 332 yards

respectively from the overflow, were noticed in the dam, and supposed to be due to changes in temperature, as they were also apparent during the preceding winter. These caused the discharge of the springs to increase to 2·6 cubic feet per second. By the 4th December, 1883, the reservoir had only been filled up to a level of 1,197 feet, but after that date the filling proceeded at a greater rate, owing to the utilization of the waters of the River Moselle.

On the 14th March, 1884, when the level of the water in the reservoir was 1,210 feet, a length of 444 feet of the dam suddenly assumed a bent form between the points 119 yards and 267 yards, and the flow of the springs increased from 2·6 cubic feet per second to 8·1 cubic feet per second. The height of the water in the reservoir was kept constant for a year after this. No further movement took place, and the flow of the springs remained nearly the same.

In 1885 a bore-hole was put down on the lower side of the dam, and afterwards the reservoir was emptied to ascertain what had actually happened. It was found that the dam had separated from the masonry wall beneath it between the points 148 yards and 247 yards, still keeping vertical, the greatest deviation from the straight being 1·1 foot at the centre of deflection. On the inner face, at each end of the displaced length, was a group of fissures. That on the right from the inside, only visible on that face, consisted of three cracks at the points 117 yards, 123 yards, and 130 yards from the overflow respectively, descending obliquely to the base of the dam, the last one joining the horizontal crack by a ramification. On the left were four cracks visible on the inside face—the temperature crack at 243 yards, which went vertically through the dam to the outside face, as also did the crack at 267 yards. The crack at 256 yards was vertical, but visible only on the inner face, and finally a fissure inclined at about 45° at 267 yards, which cut at its base the fissure at 256 yards, and joined the horizontal fracture. The cracks at the centre of the deflection were visible only on the outer face.

The formation beneath the displaced part of the dam was dislocated for two or three yards in depth, and two crevices were noticed from which springs issued, also deposits of clay, in lenticular beds, which usually were less than $\frac{1}{10}$ inch in thickness; above the dam, fissured and permeable beds were found which passed beneath the foundations of the guard wall.

Following the recommendations of a special commission of the Ponts et Chaussées, it was resolved to form an abutment of masonry on to the solid rock at the outer toe of the dam, starting at the level 1,182·4 feet, drains being laid through the masonry to lead away any water percolating underneath the dam. A wall of masonry was to be built on the water side at the junction of the guard wall and the masonry of the dam proper, and covered with puddled clay to a depth of about 3 yards. Wherever the cement plastering had become detached, the joints were to be raked out and filled with

cement mortar. The fissures also were to be filled with cement mortar, or cement grout when difficult of access.

The tubes lining the boring on the lower side of the dam were carried up above ground level, so that as the water rose in the reservoir its height in this tube could be gauged.

These works of repair were executed in 1888 and 1889, being completed on September 14th, 1889; the Fig. gives the amended section in full lines. The filling of the reservoir was recommenced on the 18th November, 1889.

The flow of the springs increased from 0·5 cubic foot per second, to start with, to 2·8 cubic feet per second, on 15th May, 1890, when the level of the water in the reservoir was 1,218·5 feet above datum, that in the tube lining the bore-hole being 38·4 feet lower. The level of the water in the tube followed that in the reservoir as the latter filled.

The deflection of the two points distant 193 yards and 267 yards from the overflow, the middle and one end of the portion displaced in 1884, was read by means of a theodolite.

The reservoir began to be used for feeding the Canal de l'Est on 15th May, 1890. The level of the water was raised each year to 1,218·5 feet, and was never lower than 1,201·6 feet. The flow of the springs varied from 1·4 cubic foot per second to 2·6 cubic feet per second. The maximum level of the water in the tube was 1,184·4 feet, and it was never lower than 1,179·5 feet.

The point at 193 yards deflected 0·32 inch to 0·72 inch, and the point at 267 yards from 0·04 inch to 0·25 inch. The vertical fissures opened in the winter and closed in the summer, attaining a maximum width of 0·28 inch. On the 27th April, 1895, at a quarter to six o'clock A.M., when the level of the water in the reservoir was 1,218·2 feet, a length of 594 feet of the central part of the dam was suddenly overturned at the level 1,186 feet, between the points at the distances 149 yards and 347 yards respectively. This length includes all but 90 feet of the part that was displaced in 1884. The fracture was nearly level longitudinally, and transversely it was level for 12 feet and then dipped towards the outside. The foundation had not moved, and the masonry was found to be of good quality.

The commission appointed to inquire into the cause of the disaster calculated, according to Mr. Bouvier's formulas, the maximum intensities of pressure in the dam for the provisional and ultimate height of the water in the reservoir, and for an additional elevation in its level of 1·6 foot to allow for the highest possible overflow-level; and the results are given in the accompanying diagram for the ultimate height of the water. The weight of the masonry was taken as 125 lbs. per cubic foot. With the ultimate height of the water, at the level 1,182·4 feet, this method of calculation gave a maximum intensity of pressure of 7·3 tons per square foot, and a ratio of water-pressure to weight of masonry above that joint of 0·695 with the extra elevation

of 1·6 foot, a maximum pressure of 10·6 tons per square foot, and the above ratio of 0·736.

Mr. Bouvier gives the maximum intensity of pressure in five dams as follows:—

Name.	Date of Construction.	Height of Water in Reservoir.	Maximum Stress in Masonry.
		Feet.	Tons per Sq. Ft.
Gouffre d'Enfer	1861–1886	164	8·6
Tournay, before raising	1861–1867	116	8·5
„ after raising 3·3 feet . .	1861–1867	119	11·0
Ban	1866–1870	148	10·0
Pas de Riot.	1873–1878	110	9·1
Chartrain	1888–1893	151	9·4

Thus the maximum pressure in the amended dam at the level of 1,182·4 feet, calculated in this manner, was less than in the above five dams. But an examination of the diagram showed that the resultant fell outside the middle third of the section; therefore if the dam below this level (the point at which the strengthening began) was considered as fixed, and the stresses worked out in the usual way for the joint at the level of 1,182·4 feet, the maximum vertical pressure thus found was 4·6 tons per square foot, and the maximum tension 1·3 ton per square foot; and for the joint 3·3 feet above, the maximum pressure and tension were respectively 4·3 tons per square foot, and 1·0 ton per square foot.

The cracks in the dam had not been properly filled with cement grout, as had been proposed, because they were, for the most part, very narrow and would not take it, but they had been closed on the face by means of tarred yarn fixed with wooden wedges. This left the interior of the fissures still open. The vertical fissures were not harmful, but the one at 267 yards communicated with the oblique crack, and dangerous uplift was caused at that point. If the fissure had a depth of five feet the maximum pressure in that section would be 18·1 tons per square foot; if it had a depth of 10 feet the resultant pressure would be outside the dam at this section. It thus appeared that the oblique fissure at 267 yards could determine the rupture of the dam for some yards in length, unless the support this portion received from the adjoining parts kept it in position. The results stated above showed that the remainder of the dam was in a state of tension on the inside face at the joint at a level of 1,182·4 feet, and for some distance above. In the first season's work the dam was built up to the level of 1,187·0 feet, and about 18 inches was taken down on re-starting work the next season, consequently a weak place at the junction of the two seasons' work occurred at the same section in which tension existed. It appeared that the dam gave way at the oblique fissure

first, and brought the remainder of the 594 feet, which was in a state of excessive strain, with it. This coincided with the evidence of the only eye-witness, and with the state of the dam after the accident.

The commission agreed that if the provisional level, for which the dam was approved, had been adhered to, no serious accident would have happened, as in that case there would have been no tension. The following are the conclusions of the commission:—

(1) The masonry of the Bouzey dam was exposed to tensions which exceeded its powers of resistance, on account of the defective adhesion of the part built in 1880 to that built in 1879.

(2) The catastrophe of Bouzey shows that it is necessary to so design reservoir dams that the masonry is not exposed to any tension.

(3) In case of such accidents as that at Bouzey in 1884 there should be no hesitation in rebuilding entirely all portions of the masonry in which there are fissures which might give rise to uplift.

(4) The conditions of stability of existing dams should be inquired into, and if necessary the level of the water reduced so as to do away with all tension in the masonry.

A. W. B.

The Municipal Waterworks of Berlin.[1]

(Gesundheits-Ingenieur, 1896, p. 122.)

An account is given of the progress of the works, now in course of construction, on Lake Müggel and at Lichtenburg, during the years 1894–95; the works at Stralau are being demolished, and any materials capable of being reused are being removed to the Lake Müggel site. The number of building-blocks connected with the mains was 23,428, an increase of 1·67 per cent.; the population served (each block being reckoned at 72·9 inhabitants) amounted at the end of the year to 1,703,481, an increase of 1·75 per cent. The water supplied from the Tegel-Charlottenburg works amounted to 5,345 million gallons, and from the Lake Müggel-Lichtenburg works to 4,908 million gallons; a total of 10,253 million gallons. An analysis follows of the various uses of the water, assuming the total supply to be 90 per cent. of the above volume, to account for difference between the quantity measured at the works and that dealt with by meter. The average consumption per head was 14·9 gallons. The maximum volume of water used in one day was 36·3 million gallons on July 7th, 1894, and the minimum quantity used in the day was 18·4 million gallons on January 1st, 1895. Statistics are given of the amount of coal consumed at the

[1] Minutes of Proceedings Inst. C.E., vol. cxix. p. 236.

pumping-stations and the duty per ton of coal. The total receipts from all sources were £357,132, and the total expenditure was £258,497. An estimate follows of the approximate outlay on the extensions and upon the new works now in hand.

G. R. R.

Observations upon Filters of various kinds. By F. Breyer.[1]

(Gesundheits-Ingenieur, 1896, p. 90.)

After very numerous experiments with many different kinds of filters, and among others upon the apparatus exhibited in the summer of 1895 at Paris, on the occasion of the international competition, when thirty-five different filters were tested in the specially erected house on the Quai d'Austerlitz, the Author arranges these appliances in three groups:—

Group A. Consisting of those filters which rely mainly upon chemical action, and in which an effort is made to purify the water by means of preparations of iron, alum, or permanganate of potash.

Group B. Including sand-filters, filled with coarse and fine sand, and animal or vegetable charcoal; and

Group C. Comprising hollow calcined cylinders of porcelain, or similar cells of artificially-moulded substances; likewise filters composed of porous plates of paper or asbestos, which furnished the principal types of the competing systems at Paris.

It is pointed out that when chemical substances are added to water in so dilute a state as to have no injurious action upon the human organism, their effect upon bacteria is extremely problematical, and on this account no further notice is taken of the apparatus included in group A. The chief advantage possessed by the filters in group B is the large area of their interstices, which adapts them for dealing with water containing considerable proportions of sediment. While, however, from the point of view of the retention of the bacteria, filters of this kind leave much to be desired, it must be admitted that the apparatus included in group C, owing to the difficulty and costliness of the cleansing process, hitherto has given but a poor substitute for the sand-filters and the appliances included in the second group. Reference is made to two filters exhibited by the Author at the Paris competition, which gave excellent results in the outset. Owing, however, to the great numbers of bacteria, and the sticky fat-like impurities present in the water, the pores of the filter-material became stopped up, and even the brushes employed to cleanse the surface of the filter became clogged, so that in lieu of removing the accumulations, they actually spread them over the surface as though they were a coat of paint. These evils induced

---

[1] Minutes of Proceedings Inst. C.E., vol. lxxxv. p. 470.

the Author to undertake the improvement of the action of his filter, which consists of compressed asbestos plates, and he employed a dust of very finely-ground straw particles, which, after being subjected to a very simple treatment, have the same specific gravity as the fine asbestos powder. This preparation is added to the water, and is at once automatically spread over the surface of the filtering-plates, and furnishes a protective layer which prevents the entry of the fine particles of slime, &c., into the pores of the filter. It can from time to time be readily washed off by a jet of water, and speedily be renewed. This formation of a special external coating of fine particles, automatically applied, renders the use of brushes only necessary in very special cases, and reduces the cost of cleansing the filter to a minimum.

G. R. R.

Sandstone-Slab Filters on the Fisher System at Worms.

By Dr. Schöfer.

(Mittheilungen über Gegenstände des Artillerie- und Genie-Wesens, 1896, p. 265.)

The Author, having been deputed in the autumn of 1895 to study Fisher's system of filtration through slabs of porous artificial sandstone, which had been for some time in operation at Worms and Magdeburg, gives an account of this process by reference to a diagram which shows a filter-plant of sixty cells in plan and section. The inquiry was undertaken on behalf of the New Vienna Waterworks Company, who propose to employ this process in lieu of sand-filters, as arranged for their works now in progress at the Wolfsgraben reservoir. The importance of thorough filtration through sand is insisted upon, and reference is made to the beneficial employment of filters in the case of Altona, in connection with the cholera outbreak at Hamburg, and to the immunity from this disease enjoyed by Berlin and Magdeburg from the same cause, in spite of the respective pollution of the Spree and the Saale by the dejections of cholera patients. Imperfect and improperly conducted sand-filtration, on the other hand, does not intercept the disease-germs, and cases are given where epidemics of cholera and typhoid fever have been ascribed to the careless management of the filter-beds. In consequence of the fact that the effective work of the sand-filter is all done in the topmost layer of fine sand, that impurities do not penetrate to a greater depth than a fraction of an inch, and that the deeper layers only serve to support the superficial sand, Mr. F. Fisher, the director of the Worms Waterworks, conceived the idea of reducing the thickness of the fine sand and of consolidating the same into slabs in order to reduce the mass of the filter. He succeeded in producing slabs of artificial sandstone, each 3 feet 3 inches square by 3·9 inches thick, by cementing together fine sand with a readily fusible silicate. These slabs were screwed together

in pairs, having between them round the edges a layer of cement 3·1 inches broad by 0·73 inch thick, so that a hollow space was formed, into the side of which a metal pipe was inserted. It has recently become possible to make the slabs all in one piece, and thus to avoid the necessity for joining two slabs together. Any number of these filter-cells can be placed together side by side in a vertical position, and the water surrounding them is forced into the central hollow space, the hydraulic head causing it to pass through the 3-inch walls of the chamber. Various methods of working the filter when the collecting-pipe for the filtered water is above or below are given. The cells are grouped together into so-called "batteries," and provision is made for isolating the produce of each battery for testing purposes. Professor Bessel-Hagen has carried out a series of experiments with these sandstone-filters as compared with ordinary sand-filters, and he states that the results obtained are equally good as respects purity of the effluent, and much superior if the yield for a given filter-area is taken into account. Since this system was started the speed of filtration has been reduced to 5 cubic metres per twenty-four hours, and the number of germs per cubic centimetre has been thus greatly reduced. The following Table shows the comparative efficiency of both kinds of filters:—

Number of germs in 1 cubic centimetre of filtrate in 1894.	Sand-Filter.		Sandstone-Filter.	
	July.	August.	July.	August.
Smallest	4	6	13	14
Largest	250	87	56	87
Average	27	20	32	37
Mean of all filters used	40	24	35	24

An account is given of the manufacture and testing of the slabs. They are made by heating together, at a temperature of 1,200° C., fine sand from the Rhine and finely-ground soda-water-bottle glass. The plant at Magdeburg, which consists of 720 cells and yields 792,000 gallons per diem, has given very satisfactory results. Smaller plants on this system are in operation at Kochem and Andernach, and an experimental filter of 60 cells is being erected at the Berlin Waterworks on Lake Müggel, where the immunity from stoppage by frost of a covered filter on this system, if it is found to succeed, is an important consideration.

G. R. R.

Experiments to demonstrate the Presence of Vibrios, resembling those of Cholera, in Water-courses.

By Dr. O. NEUMANN and Dr. E. ORTH.

(Zeitschrift für Hygiene, 1896, p. 363.)

An account is given of 557 tests of water taken from the Elbe and its tributaries in the vicinity of Hamburg during 1894 and 1895; the localities are explained by references to a map. These tests were made in order to carry on the investigations of Dunbar, who had demonstrated that while, during the earlier months of the year 1893, vibrios, resembling those of cholera, were never present in the river water, in the months of July, August, and September, such vibrios were found in considerable numbers. The experiments conducted by the Authors extended also to sewage water, and to the drainage from pig-sties, cow-sheds, and dung-heaps. A detailed description is given of the mode of taking the samples, and of carrying out the tests, by cultivation on gelatine and on agar. A certain proportion of the cultures were obtained by means of spraying, which process, after very slight practice, gave well-isolated colonies on the nutritive gelatine. The presence of phosphorescent vibrios could readily be perceived in the dark chamber, and such colonies could often be marked on the plates. The germs were then transferred by the aid of the microscope to peptone solution for cultivation at a temperature of 37° C. The further treatment of such colonies and their reaction when pure dilute sulphuric acid was added to a peptone culture, together with nitroso-indoline, is described, and it was ascertained that in a certain number of cases these vibrios did not show the characteristic red reaction. Only such colonies as behaved in all respects as do cholera-vibrios are, however, taken into consideration on the present occasion, and the results obtained are set forth in a tabulated form. During 1894 vibrios of this character were only found in August and September, when they disappeared until the same months in 1895. It is pointed out that this is just the period when cholera cases are prevalent, and though it is not yet possible to pronounce decisively on this question, it would appear that the abundance of vibrios in the river-water may have some connection with the outbreaks of cholera.

G. R. R.

The Value of Formalin (Formic Aldehyde) as a Disinfectant.

By Dr. K. Walter.

(Zeitschrift für Hygiene, 1896, p. 421.)

Some general considerations are given of the points which must have weight in deciding upon the qualities of a disinfecting material, and it is asserted that none of the substances at present known comply with all the stipulated conditions which the Author enumerates. Corrosive sublimate, for instance, notwithstanding its undoubted value as a bactericide, has the disadvantage of being highly poisonous, and of being liable to chemical decomposition. Moreover, when it comes into contact with albumen or with soap, it enters at once into inert combinations. Carbolic acid, which is likewise poisonous, and possesses a most unpleasant smell, is apt to irritate the skin. Lastly steam, which is perhaps the most readily available disinfecting agent, is difficult to employ effectively, and is liable to injure many substances exposed to its action. On the issue of the account of formalin in 1893 it seemed as if an ideal disinfectant had been discovered. Formalin was stated to be a 40 per cent. solution of formic aldehyde, a product of the oxidation of methyl alcohol, obtained by passing vapours of this substance mixed with air over a glowing spiral of platinum wire. Under these circumstances a colourless gas is generated, having a pungent odour. It is readily soluble in water, and has a strong tendency when exposed to the air to oxidise into formic acid. Its disinfecting properties are, in fact, due to this reaction. According to the investigations of Löw, Aronsohn, Trillat, and Berlioz, the 40 per cent. aqueous solution of formic aldehyde possesses the following properties:—

(1) Very great bactericide powers, even in highly dilute solutions.

(2) Very moderately toxic action.

(3) Chemical effect of rendering inert the products of putrefaction—ammonia, sulphuretted hydrogen, &c.

(4) Its solution, in the form employed, is devoid of injurious action upon the skin and upon all other substances with which it may come in contact.

(5) It is capable of being used as a solid, a liquid, or a vapour.

(6) In a concentrated state it has a peculiar action upon animal tissues which has been termed "leather-forming."

(7) It is very volatile, which enables it to be rapidly expelled when it has attained its object.

The Author quotes the previous investigations of various writers who have dealt with the properties of this disinfectant, and gives the results of his own experiments, which are set forth in a series of tables. Esmarch-tubes were employed of nutritive gelatine, to which were added solutions of various degrees of strength, containing from 2 per cent. to 1 per 100,000 parts of formalin.

Fresh bouillon-cultures of the bacilli of anthrax, cholera, typhoid-fever, and other spores were introduced into the tubes, and the results, after due cultivation, were ascertained at the end of eight days. The solution of 1 per 10,000 parts in strength was fatal in every case, while all the spores retained their vitality when the dilution was 1 per 20,000. The formalin was also tested in the gaseous state. The disinfectant was likewise used practically upon various materials and with results which are tabulated. The Author sums up the conclusions at which he arrived, which were extremely favourable to this compound, and states that formalin furnishes an excellent and readily-employed disinfectant, capable of being used for a variety of purposes. It not only supplies a want in medical practice, but it is well adapted for domestic uses, and will be most valuable in the army. It can be substituted for the steam jet, and surpasses steam in the rapidity of its action. In all cases where steam cannot be employed, as for instance in the disinfection of dwelling-rooms or of uniforms, formalin may supply its place with complete success.

G. R. R.

The Danger of Sewer-Gas and the Exclusion of the Same from Dwellings. By Dr. M. Kirchner.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, vol. xxviii., 1896, p. 152.)

At the meeting of the German Association for the Preservation of Public Health at Stuttgart, the Author opened the discussion on the subject of sewer-gas, which Dr. Fränkel had to give up in consequence of a severe attack of illness. Mr. Lindley undertook to open the discussion on the exclusion of sewer-gas from dwellings.

The Author pointed out that, according to the theory under consideration, sewer-gas was asserted to be capable of inducing grave injury to health, and was the means of spreading infectious diseases. It was concerning its activity in this latter aspect that he desired at first to treat. The authorities who had been prominent in the past in laying down the doctrine of the promulgation of diseases through the agency of sewer-gas were discussed, and the writings of Parkes, Meredith, Notter, and others were cited. It was chiefly in England that the injurious action of sewer-gases escaping into houses was insisted upon, and typhoid fever was one of the principal diseases attributed to these causes. The reports of Simon on the Sherborne epidemic in 1872 and of Buchanan on the outbreak of typhoid fever at Caius College in 1873 are quoted as representative of the opinion of English experts. In contradistinction to these views, the majority of writers on hygiene in Germany maintain that sewer-gases are incapable of disseminating typhoid fever or other infectious diseases; and, in support of these conclusions, allusion is made to the investigations of Flügge, Gärtner, Prausnitz, Rubner, and Soyka.

As early as 1881 the last-named authority demonstrated by statistics at the Vienna meeting of the society, that cities provided with sewers were not in any way more liable to the attacks of diseases of this type than those wholly undrained; indeed, he proved the converse of this theory, and showed that in a series of towns which had recently been sewered on the modern system the mortality from typhoid fever had diminished, and that, in those parts of the towns where the sewerage was defective, the cases of typhoid fever were more frequent and more severe than in those quarters which were well drained. Many other authorities were cited, and figures are given to show the condition of drained and undrained towns, among which the facts relating to Dantzig and Munich before and after the introduction of drainage are recorded, also the investigations of Baron into thirty-seven undrained towns and forty-six towns provided with a system of sewers. Everything pointed to the opinion that the provision of proper drainage is the best method of reducing the death-rate from typhoid fever; whereas, if the sewer-gas theory were correct, the construction of a modern sewerage system ought to entail increased mortality from this disease. Passing on to the discoveries of Pasteur and Koch and their numerous pupils, the Author shows that a correct knowledge has now been gained of actual disease-germs and of the best means of withstanding them. It may be pronounced with absolute certainty that any given disease can only occur when the known organism recognised as the active agent of the same has acquired vitality. In the absence of the typhoid-bacillus there can be no typhoid fever; and where there is no cholera-vibrio, there can be no cholera. The gases caused by putrefaction, however poisonous they may be, cannot produce infectious diseases of the above kind. The Author points out that certain of these pathogenic germs which may enter the sewers mixed with fecal matters and soiled water do not find in them very favourable conditions for their existence, and that for the most part these organisms lose their virulence in sewage water. In order that the sewer-gas theory may be realised, it must, however, be assumed that certain of these infectious germs are capable of floating in the air and of thus entering into dwellings. Nägeli has, however, shown that this is not possible, and he has proved that these germs can neither ascend into the air nor be given off from moist surfaces, and in the air of sewers, moreover, bacteria have been ascertained to be invariably present in small numbers; indeed, frequently such air is absolutely free from these organisms. Uffelmann has been at some pains to ascertain the species of bacilli found in sewer-gas, and a list of these is given. It is stated that it follows from these arguments that there is no proof of there being any connection between sewer-gas and the spread of epidemic diseases.

On the question of the extent to which, apart from their liability to spread diseases, sewer-gases may prove injurious to health, the Author asserts that this depends mainly on the degree

of concentration in which certain undoubtedly poisonous gases exist which are found in sewers and other places where putrefying matters are collected and stored. The thorough and effective ventilation of sewers and soil-pipes is the best mode of combating this evil.

A distinction is drawn between sewer-air and sewer-gas, and it is pointed out that the latter can only form in sewers which contain dead-ends and in other places where effective ventilation is wanting. In well-constructed sewers, the contents pass away freely and rapidly without undergoing putrefaction, and the air in such sewers is in no way unhealthy. The house-drains and soil-pipes are much more likely to engender evil-smelling and injurious gases than are the sewers.

G. R. R.

The Cholera in Hamburg. By Prof. Dr. v. PETTENKOFER.

(Gesundheits-Ingenieur, 1896, p. 88.)

Reference is made to the recent issue of two important publications relating to the violent outbreak of cholera in Hamburg in 1892, the one by Dr. Gaffky and the other by Dr. F. Wolter. Both of these authorities start with the same statistical data, but they arrive at diametrically opposite results as to the cause of the epidemic, and as to the value of the measures adopted to combat the disease. Dr. Gaffky takes up his stand entirely on the bacteriological (contagious) theory, and regards the outbreak to have been caused by the introduction of the cholera-vibrio, spoken of as x by the Author. This germ having been by some means conveyed into the water-supply is all that is needed, he considers, to bring about an epidemic; granted that there is an individual disposition or tendency to become infected, this disposition being here represented by the factor z. Dr. Wolter, with whose views the Author declares himself to be in accord, though he has not ventured to promulgate them, pronounces in favour of the epidemiological theory, and he assumes that neither the importation of the cholera-vibrio into any locality nor the individual disposition of its inhabitants to succumb to the attack, is sufficient to account for the disease; but that there is still a third factor which depends upon local and periodical conditions, which are here set down as being the partly unknown quantity y. Dr. Wolter divides his work into two sections—the one relates to all previous cholera outbreaks in Hamburg (fourteen in number), the other to the epidemic of 1892. He says, concerning this last, that it coincided in point of time with similar outbreaks in Northern and Western Europe, and that the most searching investigations have failed to discover how and whence the vibrio was imported. No cholera germs were ever found in the Elbe or in the drinking water. The disease followed

much the same course as previous attacks; it broke out as they did in the vicinity of the port, in the Grasbrook quarter, and in point of severity it agrees well with former visitations of the cholera; the mortality having been 11·29 per thousand in 1832, 10·59 per thousand in 1848, and 13·44 per thousand in 1892. The school of Koch and the majority of the bacteriologists assume that the outbreak of 1892 was caused by drinking water infected with cholera-vibrios; but judging by what took place both on this and on former occasions when there was no public water-supply, Dr. Wolter asserts that there is no confirmation of the opinion that the disease was distributed by means of the water-mains. According to the Author, the waterworks had nothing to do with the spreading of the cholera-vibrios, but he believes that the impure water contributed to the pollution of the subsoil and the dwellings. Foul water cannot be relied upon to cleanse anything, and for this reason he has urged the construction of filter-beds. Moreover, although he does not accept the theory of infectious germs, he is convinced that the use of impure water renders the users more disposed to attacks of illness and also to cholera. The question of the contagious character of the epidemic is statistically analysed by Dr. Wolter, and he concedes the fact that probably one quarter of the cases at Hamburg in 1892 were due to this cause; but this opinion is combated by the Author. The cholera-vibrio theory has made many converts, but the views of Simon, Griesinger, James and Douglas Cunningham, and Lewis are quoted in support of the belief that the spread of the disease is due to a variety of contributory causes. To guard against cholera, it is necessary to work in advance; when once the outbreak has occurred, it does not matter to what extent isolation and disinfection are undertaken. Many continental towns, including Berlin and Munich, have taken such sanitary precautions that they may hope in the future for the immunity from cholera enjoyed by certain of the best drained English cities since 1866. It is, the Author says, much to be wished that the millions of money, which he deems have been wasted in Hamburg upon precautionary measures from the point of view of contagion, had been expended in cleansing human dwellings; and the work of Dr. Wolter will have considerable weight in bringing this opinion into prominence.

G. R. R.

Cost and Working Expenses of the Breslau Sewage-Irrigation Works. By v. Scholtz.

(Gesundheits-Ingenieur, January 31, 1896, p. 23.)

These works, which have been in operation since 1881,[1] are situated to the north-west of the town. The present contributory

[1] Minutes of Proceedings Inst. C.E., vol. lix. p. 360.

population is about 355,000, and the whole of the sewage is brought to one point, where it is pumped on to the land through a rising main, about 705 yards in length, with a lift of 21·3 feet. The land used for irrigation purposes is situated along the banks of the Oder, and it is at such a level as to need to be protected from floods by a dam. During the periods of floods the effluent water has to be discharged over the dam by pumps, with a lift of about 11·5 feet. The total area of the irrigated land with all adjuncts is about 1,671·7 acres. The cost of land and the laying out of the same together with pumping station is set down at £163,500. The land is let to tenants who pay rent for use of sewage.

		£
The annual working cost incidental to the land is .	£738	
The receipts from tenants of the irrigated land equal	£3,448	
	£3,448 − 738 =	2,710
Interest and sinking fund on £163,500 at 4 per cent. . . .		6,540
Entailing an annual outlay of £6,540 − 2,710		=3,830

$$\frac{3{,}830}{355{,}000} = \text{annual cost per head, } 2\cdot 59d.$$

Cost of pumping-station and raising sewage on to land, including houses for staff, &c.	£27,000	
Interest and depreciation on £27,000 at 8 per cent. . . .		2,160
Annual working cost		1,750
		£3,910

$$\frac{3{,}910}{355{,}000} = \text{annual cost per head, } 2\cdot 64d.$$

$$2\cdot 59 + 2\cdot 64 = 5\cdot 23d. \text{ per head per annum.}$$

This represents the total cost of dealing with the sewage of Breslau by irrigation. In order to provide for increase of population, a property adjoining the present estate has been recently acquired.

G. R. R.

The Products of Combustion of Gas-Flames. By Dr. H. Bunte.

(Journal für Gasbeleuchtung, 1895, p. 449.)

The frequent complaints made as to the injurious effects of gas-lighting upon health, and the wide-spread idea, even among chemists, that, under normal conditions, gas-flames develop products of imperfect combustion, induced the Author to again investigate this question. In making the experiments care was taken to preserve the normal shapes of the flames, and to test the products of combustion without further dilution with atmospheric

air. This was effected in a simple manner by fixing a metal funnel over the flame, as near to it as possible, without disturbing the stream of gas, and by drawing off any required portion of the products of combustion through a tube fixed in the side of the funnel neck. The products of combustion fill the conical portion of the funnel, and escape under the lower edge of the same, so that, without disturbing the burner, a portion of the gases can be continually drawn off for testing. Chimneys with flames at smoking point were also tested to determine what excess of air, under these conditions, passes through the chimney with the burnt gases. For this a London Argand burner was used, and compared with two petroleum burners with the following results:—

——	Carbonic Acid.	Oxygen.	Nitrogen.
	Per Cent.	Per Cent.	Per Cent.
5 cubic feet per hour Argand burner . .	11·1	3·8	85·1
Petroleum burner	9·9	7·3	82·8
" "	9·6	7·9	82·5

If the so-called coefficients of excess are calculated from these, it is found that with such cylinder-burners there is an excess of air with the Argand burner of 1·2, and with the petroleum burners of 1·5 and 1·55, so that with a good Argand burner, at smoking point, the consumption of the air is practically perfect. With incandescent gas-burners the relations are somewhat different. The burning of the gas takes place after mixture with air, and the flame is principally developed in the zone formed by the incandescent mantle. The more perfectly this zone of intense burning coincides with the surface of the incandescent body, the higher the latter is heated, and the greater will be the illuminating power, apart from other circumstances, which depend upon the composition of the mantle. That this is the case is proved by testing the burning gases immediately above the suspending point of the mantle; at a distance of 0·20 inch 12·6 per cent. of carbonic acid and 0·3 per cent. of oxygen were found, and a very small excess of air, while in the interior of the mantle the products of imperfect combustion found were 11·6 per cent. of carbonic acid and 3·8 per cent. of carbonic oxide. In addition to the air necessary for combustion a considerable excess is drawn through the chimney, so that the products of combustion passing from the chimney show a considerably lower proportion of carbonic acid.

To determine whether, under normal conditions, imperfectly consumed gas escapes with the products of combustion, a portion of these products were passed through a series of apparatus, in which the carbonic acid and moisture were absorbed, then any existing partially consumed gas was passed through red-hot copper oxide and completely burnt, the weight being ascertained in the next

apparatus. Ten trials were made in this way with Welsbach burners, some having damaged mantles. Ten tests were also made with Argand burners, hollow-top slit burners, and round wick petroleum burners, the result being that with all the burners the increase of weight, indicating the presence of imperfectly-consumed gases, especially carbonic oxide, was so small that the variations were within the limits of errors of observation, and the consumption may be regarded as having been perfect.

With heating-flames, in contact with bodies to be heated, in order to obtain perfect combustion, it is absolutely necessary to previously mix the gas and air; the greater the amount of primary air added, the easier it is to obtain, under otherwise equal conditions, perfect combustion, even with a limited admission of "secondary air" and the rapid cooling of the flame by cold vessels. With burners of French origin that were tried the air-mixture was too small, and consequently a considerable quantity of imperfectly consumed gas was found. Two German and two French cookers were tested, and also a single Bunsen burner, with air adjustment. The two German cookers, with mixtures containing 23·9 per cent. and 25·8 per cent. of gas, yielded 8 per cent. and 7·2 per cent. of carbonic acid, and only 0·029 per cent. and 0·072 per cent. of unconsumed gases, estimated as carbonic oxide; while the French cookers, using 40 per cent. and 48·5 per cent. of gas, gave 7·4 per cent. and 7·8 per cent. of carbonic acid and 0·468 per cent. and 0·546 per cent. of unconsumed gases. The Bunsen burner, with proportions of gas varying from 20 per cent. to 78·2 per cent. of gas, yielded from 6·7 per cent. to 6·5 per cent. of carbonic acid, and 0·04 per cent. to 0·51 per cent. of unconsumed gases. Different makes of incandescent burners, which may be regarded as heating burners, were also tried, and the proportions of gas were found to vary between 22·5 per cent. and 29·2 per cent. With all these burners the admixture of air amounted to at least 70 per cent., which is so near to the theoretical amount that the combustion may be assumed to have been complete.

C. G.

The Railways of Bosnia, the Herzegovina, Servia and Bulgaria.

By Julius Seefehlner.

(Deutsche Bauzeitung, 1895, p. 513.)

The first portion of the Novi-Banjaluka line was made in 1871–72 and completed in 1875, the length being 65 miles. The curves adopted were sharp and the gradients steep with the object of minimising the cost of earthwork and of bridges. These latter were of timber, and the wrought-iron rails weighed 69 lbs. per yard. The line was unfenced, and the signalling arrangements were of the very simplest character. The completion of

the line at the northern end, on Croatian territory, was in 1881 when it became part of the Austro-Hungarian system. The original rails have been replaced by those of steel weighing 71 lbs. per yard, and the bridges have been reconstructed in masonry and iron. The gauge of this line is 4 feet 8½ inches, and the minimum radius of curves is 15 chains. Table No. 1 gives the details of the above railway and of other Bosnian lines, including the Brod and Sarajevo Railway, either worked by adhesion or on the rack-rail system, as also two with wire rope. The gauge varies from the normal to 2 feet 6 inches and 2 feet, the greater portion, however, being to the 2 feet 6 inches gauge.

The B. Brod and Sarajevo line was commenced in 1878. It is of 2 feet 6 inches gauge, and 166 miles in length. It was constructed very rapidly and roughly, and for some time after its opening was only fit for goods traffic. The rails were of various sections weighing from 28 lbs. to 35½ lbs. per yard, now replaced by steel rails of 35½ lbs. per yard.

It crosses the River Save by a bridge of five openings, each of 262 feet 6 inches span, with wrought-iron lattice girders on timber piers; at each end of the bridge were numerous land spans of timber construction. It being found later on that the headway for navigation was insufficient, in 1882–83 the girders were raised, and at the same time the piers reconstructed and the above-mentioned land spans filled in with embankment. The line is worked by locomotives which, on grades of 1 in 200 with a speed of 15½ miles per hour, have a haulage power of 200 tons, and, on grades of 1 in 70 with a speed of 9¼ miles, have a haulage of 120 tons.

The line is divided into two sections, viz., from B. Brod to Zenica, and from Zenica to Sarajevo. The cost for the first section was £4,924 per mile and for the second section £6,665 per mile.

The gauge of the Doboj, Dolnje, Tuzla, Simin, Hann Railway is 2 feet 6 inches, the length 41½ miles, and the cost per mile £2,150.

The Metkovie, Mostar, Sarajevo Railway was commenced in 1885 and opened throughout its length in 1891. The gauge is 2 feet 6 inches and the length 110½ miles, of which 9⅓ miles are laid with the Abt rack rail, being where the water-divide of the Narenta and the Save is crossed. The cost varied from £5,064 per mile and £3,558 per mile. There are sixty-five tunnels, with a total length of 2,228 yards, and twenty-nine stations. On the adhesion length the steel rails weigh 36 lbs. per yard, and on the rack rail portion 44 lbs. per yard.

The Lasva, Travnik, Bugojni, Jaicze Railway is 62 miles in length, of which 3 miles is laid with a rack rail. The cost was £9,890 per mile.

The total length of main-line railways in Bosnia and the Herzegovina opened for general traffic is 448 miles, in addition to which there are 64 miles of subsidiary lines and 2 miles of horse-tramway between the station and town at Sarajevo.

The total length of the Servian railway system is 338 miles,

and the average cost per mile £11,995. They were opened for traffic during the period extending from 1884 to 1887.

The existing railways in Bulgaria have a total length of 517 miles, those in construction 20 miles, and a further length of 315 miles of projected lines. The gauge is 4 feet 8½ inches.

The length of railway for each 100,000 inhabitants, and length of line per 100 square kilometres, the latter varying from 0·46 kilometre, in the case of Servia to 1·29 kilometre for Hungary.

The number of locomotives, which varies from 0·096 per mile in Bosnia to 0·22 per mile in Hungary, of passenger carriages varying similarly from 0·56 per mile to 0·37 per mile, and of goods wagons, viz., from 2·36 per mile to 6·44 per mile.

D. G.

Underground Railway at Paris.

By — Brière and — De La Brosse.

(Revue générale des Chemins de fer, November, 1895, p. 187.)

This underground line is an extension of the Orleans Railway from its previous terminus at Denfert-Rochereau towards the centre of Paris, and is, the Authors state, the first metropolitan underground line of Paris. Its total length is 1 mile 607 yards, of which 1 mile 187 yards are in tunnel. Starting from the bridge over the Rue de la Tombe-Issoire, it goes under and follows the Rue Denfert, the Avenue de l'Observatoire, and the Boulevard St. Michel, terminating in the latter. The sharpest curve has a radius of 11¼ chains, and the steepest gradient is 1 in 47·6 for a length of 258 yards. The gradients follow the street gradients as far as Port-Royal station, but beyond this point the gradient is steeper than that of the Boulevard St. Michel, having in view a future extension towards the Seine without any gradients steeper than 1 in 50.

The object throughout has been as far as possible to construct the tunnel in masonry, and iron has only been used where the headway was limited. The following are the principal dimensions of the tunnel in masonry:—

	Feet.
Span	29·53
Rise of arch	10·27
Height of springer above rail-level	9·41
Total height from rail-level to crown of arch	19·68
Thickness of the abutments	4·59
" " arch at the crown	2·13

The masonry of the arch-ring is built in Portland-cement mortar, and the extrados is covered with a layer of cement mortar $1\frac{3}{16}$ inch in thickness, and a layer of asphalt $\frac{19}{32}$ inch in thickness. Although a span of 26·25 feet was specified it was altered to 29·53 feet, in

order to increase the amount of air and to facilitate the work of the platelayers. Refuges are built on each side at a distance of 66 feet from each other, and are 6·56 feet in width, 2·62 feet in depth, and 7·54 feet in height.

A length of 197 feet of the railway has been covered with iron; this portion has a minimum height of 15·75 feet above rail-level, the girders are spaced 9·84 feet centre to centre, and are 2·95 feet in depth; brick jack-arches, 0·72 foot in thickness, are built between the girders with concrete backing. The abutments are 4·92 feet in thickness.

There are three stations, namely, Paris-Denfert, Port-Royal and Luxembourg. The platforms are 197 yards in length; at first one island platform at each station was proposed, but the idea was abandoned on account of the serious inconvenience which would arise in controlling large crowds of people, and there are therefore two platforms at each station. The coping of the platforms is 2·89 feet above rail-level, and is 2·48 feet from the centre of the nearest rail. This height gave rise to a considerable amount of discussion between the representatives of various railway companies and the Administration of Public Works, and also to a series of tests, in view of the possibility that in the future carriages belonging to other companies would be used on the line; and the section of the platform was therefore arranged so that the existing rolling-stock, built with foot-boards to suit the ordinary platforms, 0·82 foot in height, could be used. The overhang of the coping in front of the platform wall is 1·97 foot; the coping is composed of volcanic slabs (*dalle en lave de volvic*) which have the property of never becoming polished or slippery. Separate exit and entry staircases are provided for each platform.

The line passes the Paris Observatory at a distance from it of about 109 yards, and considerable opposition on the part of the authorities was met with, who feared that the vibrations produced by the trains would seriously affect their astronomical observations, and the following stipulations were enforced on behalf of the Observatory authorities.

1st. The depth of the ballast to be 3·28 feet for the whole distance between the Denfert and Port-Royal stations.

2nd. A protecting wall, 3·28 feet in thickness, to be interposed between the tunnel and the face of the houses throughout the same length; this wall, which goes down to the level of the invert, was formed with sand carefully punned.

3rd. On the top of the invert—or, on the top of the earthwork in places where there was no invert—a layer of asphalt-cement, 0·33 foot in thickness, to be laid. The asphalt-cement is formed of 1 cubic yard of clean pebbles to 18 cwt. of bituminous cement, similar to that used for the footpaths of the town. Special care was taken in its formation, and the pebbles were subjected to a temperature of about 266° F. in order to ensure their adherence to the bituminous cement. This work, by the Compagnie Générale des Asphaltes de France, cost £4 11*s.* per cubic yard.

4th. The ends of the rails to be cut to form a bevelled joint in order to diminish the shocks at the joints. Up to the present this stipulation has not been enforced, as the Authors were of opinion that this method would be more harmful than useful, and that it was of the highest importance to have as strong and stable a joint as possible, and that with the type of permanent way adopted this result is obtained.

5th. The roadway of the Rue Denfert-Rochereau to be paved with wood in place of the existing stone setts.

The total cost of these requirements amounted to £7,200.

With regard to ventilation, the line is divided into two sections of tunnelling by an open cutting at Port-Royal Station, 95 yards in length. The first section from Paris-Denfert to Port-Royal is 781 yards in length, and being open at both ends ten ventilating-shafts, 1·53 foot by 2·62 feet in section, were considered sufficient. These starting from the top of one side of the tunnel terminated at the base of kiosks placed on the footpaths. The second length, from Port-Royal to Luxembourg, on the other hand, presented considerable difficulty in this respect, as the Luxembourg end is completely closed, the line terminating in a cul-de-sac 219 yards beyond the station. The locomotives condense their own steam and only consume coke and briquettes, smoke and steam are thus suppressed, but the products of combustion in the form of invisible gases being always present, it was necessary to eliminate them with as much care as possible, especially as passengers would occasionally have to wait a considerable time on the platforms of the Luxembourg station. An ordinary ventilating shaft had been fixed at the station, but proved quite insufficient, and recourse was necessarily had to artificial ventilation. The principle of suction rather than forcing of air was decided upon as being the more advantageous method, and the object aimed at was to cause the fresh air to reach the tunnel at the level of the platforms, and to expel the vitiated air at the highest possible point of the tunnel, the outlets being placed midway between the inlets. Seven air-shafts, terminating in kiosks, allow the fresh air to arrive in large recesses in the abutments in the stations, and nine others are built between the two stations and in the cul-de-sac beyond. These shafts are similar to those between Paris-Denfert and Port-Royal, but in place of being the means of expelling the vitiated air they draw in the fresh air. The vitiated air is drawn through the shafts in the top of the tunnel, which are connected to a masonry gallery of variable section leading to a ventilating-fan fixed in close proximity to the Luxembourg station which expels the air through a chimney, 108 square feet in section and 85 feet in height. The total length of the galleries is 503 yards. The ventilating-fan is of the Geneste-Herscher type, with conical, cylindrical, and diverging blades, constructed specially for this line; it has two lateral mouths 5 feet in diameter. The fan-wheel is 8·20 feet in diameter, and is surrounded by a spiral spreader of increasing section, which terminates at the base

of the chimney. The total height of the appliance and spreader is 13·12 feet. The fan is worked by an electrical motor, which receives the current from the works built by the Company near Paris-Denfert station. In order to avoid vibrations—rendered more important, inasmuch as the fan works in the basement of a large building—the frame supporting the fan and motor rests on 135 insulators of the Anthoni system, laid upon a body of asphalt-cement, 2·29 feet in thickness. The result obtained is very satisfactory, the fan working twenty hours per day without causing any perceptible noise or vibrations, even in the places nearest to it. The fan makes 80 revolutions a minute, and exhausts 1,766 cubic feet of air a second, and requires about 14 HP. The total volume of the air in the tunnel between Port-Royal and the end of the cul-de-sac at Luxembourg being about 2,500,000 cubic feet, the air is renewed on an average two and a half times an hour. Instructions were given by the authorities to Mr. Grehant, chemist to the Paris Museum, to analyse the atmosphere in the tunnel at Luxembourg station. Six tests were made during June and July, 1895, and it was found that the amount of carbonic acid varied from $\frac{2}{10,000}$ to $\frac{11}{10,000}$, and that the normal proportion was $\frac{3}{10,000}$. In five out of the six tests no trace of carbonic oxide was found. In the sixth test a small trace of $\frac{1}{50,000}$ was detected, but this test was made on a Sunday afternoon, that is to say, at a time when the traffic is greater than at any other period.

With regard to the construction of the line the following stipulations were imposed: To maintain without interruption the double line of tramway which is immediately above the tunnel, and is one of the busiest in Paris (twenty-four journeys an hour in each direction); to maintain the access of vehicles to all the houses; to maintain a footpath at least 6 feet 6 inches wide in front of all buildings; to reduce to a minimum the time taken for construction in front of any one building. Owing to the small distance between the intrados of the arch and the street-level, the arch was constructed in cut and cover. As a rule only about half the arch could be turned at one time, and the method adopted was to excavate to the intrados and form the top of the dumpling to the shape of the arch. On the top of this a layer of plaster, from $\frac{3}{16}$ inch to $1\frac{3}{16}$ inch in thickness, was laid, and made true to the curvature of the arch by means of templates, this forming the centering of the arch. No wooden centres were used throughout the work. One half being turned it was covered, and, in most cases, months afterwards the other half would be built in the same way.

At the commencement of the work it was proposed to first construct one of the abutments in trenches, then the other abutment, and finally the arch ring, but it was soon recognised how laborious and troublesome this would be, especially as the trenches would be from 26 feet to 39 feet in depth. It was therefore decided to build the abutments in the following way. A trench, 13 feet in length, was sunk and the abutment built to springing level. Another trench, 26 feet distant, of the same length was sunk and the abut-

ment built. Then the site for a portion of the arch was excavated, and also the earthwork between these two pillars was excavated to form an arch in the same way, connecting the two pillars together, and the whole length of the arch-ring of the tunnel between the two pillars was then built. When the tunnel was thus completed and the excavation of the dumpling was proceeded with, great care was taken in excavating below the arch between the pillars, and in building the intervening portions of the abutments. Almost the whole length of the tunnel was constructed in this way, and no accident or failure occurred, and no settling of the arch was observed. A good sub-soil, consisting of compact sand and clay, was found everywhere, and in the final lengths the distance between the pillars was in some cases increased to 59 feet. The Authors state that, although perhaps the whole work took a little longer time to execute by this method, yet the work from the surface took a considerably less time than would otherwise have been the case, and the traffic of the streets was interfered with as little as possible. The Authors describe in great detail the various special works which had to be executed, such as the drains, sewers, gas and water mains, as well as the temporary works rendered necessary. Electrical works have been constructed at the Paris-Denfert station, and provide the electric lighting of the stations, and the power for three engine turn-tables, five lifts, the ventilating fan at Luxembourg, and a force-pump for the drainage of the tunnel. These are also fully described in the Paper. The signals include automatic fog-signals. The permanent way consists of bull-headed rails, 36 feet in length, with fish-plates curved under the bottom table of the rail. The rail weighs 85·68 lbs. per yard, and the pair of fish-plates 39·68 lbs. The rail rests in cast-iron chairs, weighing 39·68 lbs. each, which are fixed to the unpickled oak sleepers by three trenails, $\frac{13}{16}$ inch in diameter. There are fourteen sleepers per rail; a layer of felt is interposed between the chair and sleeper.

The line was opened for traffic on the 1st of April, 1895. The cost was as follows:—

	Total.	Per Mile.
	£	£
General costs of administration and salaries	30,400	22,589
Lands and compensation	58,400	43,357
Works	220,000	163,354
Permanent way, signals, &c.	12,000	8,912
Stations	17,600	13,066
Electrical installation	13,600	10,102
Total cost	352,000	261,380

Nine plates, giving full details of the stations, works, etc., are attached to the Paper.

J. A. T.

Permanent Way on the Wurtemberg State Railways.

By — v. Fuchs.

(Organ für die Fortschritte des Eisenbahnwesens, 1895, p. 239.)

The permanent way of these lines has, up to the present, consisted of rails, 29·53 feet in length, 5·12 inches in height, weighing 66·52 pounds per yard, with iron transverse sleepers of three different cross sections weighing 114·64 lbs., 125·66 lbs. and 128·53 lbs. each. At first ten sleepers to the rail were laid, then, later, eleven, and, in the case of curves less than 20 chains radius, twelve sleepers were laid; and, since 1892, these have been again increased to twelve and thirteen sleepers respectively. In spite of this increase in the number of sleepers, the cost of maintenance on the main line from Mühlacker to Ulm, 87 miles in length, rose to £48 8*s.* per mile. From fifty to one hundred and thirty-five trains, including from eight to fifteen express trains, pass over this line in the twenty-four hours, which is an increase of 50 per cent. since the permanent way was laid in 1883. In the same period the weight of the locomotives has increased from 63 tons (including tender) to 94½ tons. The gradients and curves are unfavourable; 30 per cent. of the line being on gradients between 1 in 200 and 1 in 105, and 25 per cent. between 1 in 100 and 1 in 44·5; 13·5 per cent. of the line is curved with radii between 30 chains and 17½ chains, and 2 per cent. with radii between 17 chains and 13½ chains. The difficulty of keeping the line in good repair, and the cost of maintenance, increased yearly; and eventually a commission was appointed, of which the Author was a member, to investigate the permanent way in use on foreign lines, and especially in England, and to make proposals for a strengthened permanent way.

The report of the commission emphasised the necessity of strengthening all parts of the permanent way, including the fastenings, sleepers and ballast; and the proposal was made that iron sleepers should continue to be used except in tunnels and on steep gradients. The rail adopted is flat-bottomed, weighing 87·69 pounds per yard. It is 5·51 inches in height, and the breadth of the foot is 4·92 inches, amounting approximately to 0·9 of the height. The minimum thickness of the web is 0·55 inch. The ratio of the areas of the head, foot and web is as 44·3 : 36·1 : 19·6. The surfaces of contact with the fish-plates have an inclination of 1 to 3. The standard length of the rail is 39·37 feet, but special rails, 39·17 feet long, are used for the inner rails of curves; and, in order to diminish the shocks on bridges with small spans, special rails, 59·06 feet, 29·53 feet and 24·61 feet long, are supplied.

There are sixteen sleepers under the standard rail and seventeen in the case of curves with radii less than 25 chains. The greatest distances between the sleepers from centre to centre are 2·62 feet

and 2·46 feet respectively. The distance between the joint sleepers is 1·64 foot. The sleepers and fastenings are on Heindl's system. The iron sleepers are trough-shaped with closed ends. The following are the principal dimensions:—

Length	8·86 feet
Width of top surface	5·51 inches
Total width	10·16 „
Thickness of top table	0·35 „
Maximum thickness	0·41 „
Depth	3·74 „
Weight	165·35 lbs.

The sides are thickened out at the bottom to form a strengthening band, which is 0·63 inch in height. The depth of the axis of the centre of gravity below the top table is 1·18 inch.

The angular fish-plates are 2·46 feet long, the bottom arms being shaped to avoid contact with the joint sleepers and the rail attachments on these sleepers. Six bolts, 0·94 inch in diameter, are used for each pair of fish-plates. The width of the bearing surface of the fish-plates on the rail is 0·65 inch under the head and 0·59 inch on the foot. Spring plates, according to Danischewsky's method, grip the three bolts on each side of the joint. Wedge-shaped bearing-plates, 5·83 inches long by 4·72 inches wide, of a maximum thickness of 0·43 inch, give a cant of 1 in 20 to the rail, and have a raised rim on the outer edge against which the rail-foot rests. The rail is fastened to the sleeper by two bolts, 0·83 inch in diameter, with tee-heads. The bolt passes through a binding-plate, 2·56 inches by 1·97 inch (one end of which rests on the foot of the rail), and a gauge-plate or packing, 0·63 inch in thickness, on the lower face of which is a projection which fits into the hole in the sleeper through which the tee-head of the bolt passes. There are four sizes of gauge-plates in order that the gauge may be adjusted.

For one rail joint the weights are as follows:—

	Lbs.
One inner fish-plate.	41·60
One outer fish-plate.	42·55
Six bolts at 1·764 lb.	10·58
Two spring plates at 0·397 lb.	0·79
Total . . .	95·52

Each sleeper requires:—

	Lbs.
Two bearing-plates at 2·82 lbs.	5·64
Two inner binding-plates at 0·55 lb.	1·10
Two outer binding-plates at 0·84 lb.	1·68
Four gauge-plates	3·22
Four bolts at 1·15 lb.	4·60
Four spring washers at 0·037 lb..	0·15
Total . . .	16·39

The total weight of the permanent way on straight portions and on curves of radii above 25 chains is 411·53 lbs. per yard, and on curves of radii less than 25 chains 425·38 lbs. per yard, whilst the corresponding weights of the old permanent way were 291·92 lbs. and 304·42 lbs. per yard respectively.

The Author has calculated the strains in the permanent way and gives a Table showing a maximum strain in the rail of 14·48 tons per square inch, in the sleeper of 17·27 tons per square inch, and a maximum pressure on the ballast under the centre of the sleeper, under the foot of the rails, and at the end of the sleeper, of 30 lbs., 46·79 lbs. and 27·59 lbs. per square inch respectively; all due to a wheel load of 7 tons with the tender and wagon wheels braked, to estimate the effect of which the Author has increased the wheel load 140 per cent.

A plate is annexed giving full details of the permanent way.

J. A. T.

NOTE.—The calculations of the strains in the permanent way are worked out according to Mr. von Zimmermann's work entitled "Die Berechnung des Eisenbahnoberbaues," and Mr. von Ast's report entitled "Beziehungen zwischen Gleis und rollendem Material."

Drag-shoes and Fixed Brakes at Sidings. By — BLUM.

(Organ für die Fortschritte des Eisenbahnwesens, 1896, p. 19.)

In order to obviate the danger, and in many cases provide for the absence, of the ordinary lever-brake on goods-wagons, various drag-shoes and fixed brakes on the rails have been introduced on German railways for shunting in sidings. A drag-shoe has recently been brought into use in Brunswick, which consists of a base-plate, technically called the tongue, 18·11 inches in length, on which, at a distance of 9·45 inches from its origin, is fixed the buffer or shoe, 4·49 inches in height, the surface of which is tangential to the wheel at the point of contact. The tongue is an angle bar, the upper table of which gradually increases to a thickness of 0·39 inch; the appliance is kept in position on the rail by the vertical table, 1·38 inch deep, on one side, and on the other by a spring lever rod attached to the shoe. The total weight of this drag-shoe is 13·45 lbs., and its cost is 11*s.*; it is in use at the sidings at Cologne, and had at the time the Paper was written brought 2,300 wagons to a standstill.

The Author states that great inconvenience is found in the use of all drag-shoes, inasmuch as the speed of the wagon is reduced by more or less severe joltings, which are only diminished to a small degree by the introduction of a roller under the shoe. With the object of overcoming to a great extent this defect, brakes fixed on the rail have been invented and are in use at several sidings. The Rhotert brake of this kind consists of a series of flanged bars

fixed between the sleepers on both rails, and actuated by a hand lever and rack and pinion. The movement of the bars is vertical, and thus causes the wheels to rise above the rail, being carried on the flanges of the bar; the support of the latter is so arranged as to cause the upper portion of the bar to act by pressure as a brake on the inner side of the wheel tire, and the pressure is therefore proportionate to the weight of the wagon. The rack and pinion is designed to permit the whole of the series of coupled bars—usually six in number—to be raised at one time or any less number desired. It has been found that the brakesman very readily estimates what number of bars it is necessary to bring into use for varying cases. The Author also describes a fixed brake designed by Bussing which is in use at Munich, and which is a combination of the one described and a drag-shoe, the travel of the latter being limited by the length of the brake bars; the brake lever is weighted to give a varying pressure on the wheel tires.

Illustrations of the brakes described are attached to the Paper.

J. A. T.

The Limiting-Gradients on Adhesion Tramways. By F. DENIZET.

(Annales des Ponts et Chaussées, December, 1895, p. 645.)

With the introduction of the system of overhead-wire electric traction, the gradients on which adhesion tramways are constructed have increased considerably, and in America inclines of 8 per cent. are now common, while for short distances gradients of 12 per cent. are not unknown. This the Author ascribes to two causes: first, to the gain in tractive power obtained by the use of motor-cars; and secondly, to the reduced dead-weight of the motive apparatus. If P be the locomotive dead-weight—that is to say, the weight of generator and motor on the car—and p the useful weight, including the car and passengers; v, the speed; i, the gradient; k, the relation between the power of the motor and the dead-weight P and K, a constant, the Author gives the formula:—

$$\frac{P}{p} = \frac{k\,v\,i}{K - k\,v\,i} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(i.)}$$

from which he concludes that if k can be reduced, either v or i can be proportionately increased; that is to say, a steeper gradient can be ascended at the given speed, or the given gradient climbed at an increased speed.

Mr. Denizet, however, devotes most of his attention to the consideration of the limit of gradient that can be safely descended. In his opinion, cars on an urban tramway should be always capable of stopping within a length of not more than 33 feet. While admitting that with shoe-brakes or by reversing the motors a somewhat better effect can be obtained than with slipper-brakes bearing on the rails, he considers it safe to take all methods of

braking as ultimately equivalent to sliding the car on the rails. He then obtains the following equation for the length E traversed by the car after the brakes are applied, and before coming to rest:—

$$E = \frac{v^2\sqrt{1+i^2}}{2g(f-i)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(ii.)}$$

where v = the velocity at the moment that the brakes are applied;
f = the coefficient of friction between the brakes and the rail;
g = the acceleration of gravitation;
i = the gradient (the tangent of the inclination to the horizon).

And from this, assuming $f = 0 \cdot 14$, he obtains the following safe speeds:—

3¾	miles per hour	down	a gradient of	12	per cent.
5	,,	,,	,,	10	,,
6¼	,,	,,	,,	8	,,

He discusses the possible value of f, but concludes that it should not be assumed higher than 0·14.

The conclusions arrived at are that with gradients steeper than 5 per cent.:—

1. The brakes should be of quick action and strong construction.
2. They should be in duplicate, in case of the failure of one.
3. The rails should be kept as clean and dry as possible, and sanding apparatus should be provided.

With these precautions the following speeds are perfectly safe:—

5	miles an hour	on a	6	per cent.	gradient	from	1,650	feet to	1,970	feet long.
3¾	,,	,,	8	,,	,,	,,	660	,,	980	,,
2½	,,	,,	10	,,	,,	,,	330	,,	450	,,

On steeper gradients the Author recommends the employment of cable or rack in preference to adhesion, while on longer gradients he thinks the car should be brought to rest at intervals not greater than 1,650 feet, 660 feet, and 330 feet, on gradients of 6 per cent., 8 per cent., and 10 per cent. respectively.

A Table is appended to the Paper giving various values of f and E, and also the time required to bring the car to rest calculated from equation (ii.).

R. B. M.

Fly-Wheel Governors. By Geo. T. Hanchett.

(Electrical World, vol. xxvii., 1896, p. 405.)

The Author states that there are two actions which may serve for regulating purposes in a fly-wheel governor, viz., centrifugal force of the governor weights and their inertia when in motion. Other forces also tending to move the governor mechanism are two

in number—the tension of the springs, and the pull of the valve-rod. In most cases the last-named factor is eliminated as far as possible by so designing the mechanism that the valve-rod pull comes against a rigid pin at the points where the rod is being moved.

It is important, in the Author's opinion, to so arrange the mechanism that the inertia and centrifugal effects should act coincidently, and proof is given to show that the more sudden the change of speed the quicker and more powerfully the governor will act when the *vis viva* acts in unison with the governor regulation. The centrifugal force and force of the springs should balance one another as nearly as possible, but not exactly, else unstable governing is produced.

F. B. L.

Corrosion in Boilers due to Chemical Action of Impure Feed-Water. By J. Robinson.

(Mittheilungen aus den Praxis des Dampfkessel- und Dampfmaschinen-Betriebes, 1896, p. 1.)

In the Mark (Brandenburg) District Union for Boiler Inspection, all cases of damage to boilers by purely chemical action were thoroughly investigated, samples of the feed-water, of water from the boiler after being in use some time, and of deposit from the inside of the boiler, being sent to Professor Bunte at the Chemical Technical Institute at Karlsruhe.

In the first case reported on, a boiler of the Lancashire type had been in use about a year, and was found to be severely corroded along the sides of the flues. The feed-water supplied to the boiler could be described as good; that taken from the boiler, as was to be expected, showed a considerable concentration of salts in solution. The corrosion was attributed to the decomposition of magnesium chloride on the hot plates into magnesium and hydrochloric acid; the latter, together with the oxygen and carbonic acid in the water, attacking the plates. The boiler was repaired, but nothing further is known as to its present condition.

In the second case, a boiler with two internal flues with gas firing had been in use since 1890. The shell was found to be corroded at the water-line for a width of 0·6 inch, and to a depth of 0·24 inch. The feed-water was hard, and contained a considerable quantity of gypsum. Here again the corrosion was due to concentration of salts dissolved in the feed-water, owing to the boiler being kept too long in use without blowing off. The addition of soda to the feed-water and frequent blowing-off was recommended, since which no additional corrosion has been observed.

A number of somewhat similar cases are discussed at considerable length. The Paper is accompanied by five diagrams.

A. S.

Evaporative Powers of Coke and Coal. By A. Weber.

(Mittheilungen aus den Praxis des Dampfkessel- und Dampfmaschinen-Betriebes, 1895, p. 451.)

The directors of the gas- and water-works of the town Colmar made experiments on the boiler at the pumping-station as to the relative cost of coke and coal fuel. The trials of the two fuels were made under exactly the same circumstances. Coke was used during the first week of the experiment, and coal the following week. On Monday a short preliminary trial was made; on Tuesday a trial was made after the boiler had reached its normal working condition, the trial finishing under as nearly as possible the same conditions. On each of the three following days twenty-four-hour trials were made, so that the influence of the cooling-down and heating-up losses were manifest. Finally, on Saturday another trial similar to that on Tuesday was made.

Besides observations on the fuel consumed and steam produced, temperature observations and gas analyses were made. Also a daily average sample of the fuel used was taken and its calorific values determined. The calorific values of the coke and coal were in the ratio 1 to 0·8933. The cost of coke fuel was 0·9213 times that of coal for the same amount of steam generated, showing in this case an economy of 7·87 per cent. in favour of coke.

A. S.

Electrical Condition of Underground Conductors due to Leakage Currents from Electric Railways. By W. Stuart-Smith.

(The Electrical World, vol. xxv., 1895, p. 363 *et seq.*)

The Author was instructed early in 1894 to thoroughly investigate the electrical conditions of the gas- and water-pipes in San Francisco. At that time two electric railways were at work, and a third was projected. Of the former, the oldest was the San Francisco and San Mateo Electric Railway, poorly constructed, and having its rails, it was believed, joined to the gas- and water-pipes at various points, while the other, the Metropolitan, was thought to be not so connected; as the third railway, the Market Street Railway Company, was projected, it was considered desirable to ascertain the conditions underground before it started.

In carrying out the tests, only the main gas- and water-pipes were experimented on, as it was feared the joints of the service pipes might affect the results. The pipe was bared where desired, and the difference of potential between the required points measured by Weston voltmeters. In all cases, the difference of potential between the two pipe systems and between each of them and the rails and earth respectively was determined, a bar driven into the bottom of the hole made to uncover the pipes

being used as the earth connection. Contact was made for some considerable time in each case, four to six cars being allowed to pass in order to give certainty to the readings.

The Author points out the fallacy of connecting two points by an ammeter, the conditions so established being totally different from those existing before the insertion of the instrument. He further points out that any current which may be flowing in the system under ordinary conditions is divided up among a very large number of pipes.

The Author refers to tests made by Mr. J. H. Farnham as being the only ones covering an entire area affected by leakage currents available for reference before his own, and in this case they related chiefly to telephone cables in subways touching the earth at widely separated points, and these not in close proximity to the rails, whereas the Author's experiments related to conductors buried in the ground throughout their length. Mr. Farnham determined the difference of potential between the conductor supposed to be affected and the earth; he found that with the negative pole of the railway generator connected to the rails, there was a restricted area near the station in which the conductor was positive to the earth, while in outlying parts it was negative to it. The Author endeavoured to ascertain the limits of the area in which the pipes were positive to the earth and the positions of the places where the rails were connected to the pipes. A map is given showing the course of the three railways and the situation of the generating stations. The gas-pipes do not reach the generating stations, whereas the water-pipes extend beyond them, and hence form as it were a connecting link between the gas-pipes and the stations. Two series of tests were made, the first in the dry season before the starting of the Market Street line, the second after the winter rains had begun, and the new railway had got to work.

A very large number of experiments are minutely detailed and discussed. A great part of the work was devoted to determining the presence of metallic connections between the rails and the pipes. Most contradictory results were obtained when the difference of potential between a pipe and other conductors only was taken into account, but when the drop in potential along the pipe itself was also measured, the presence of a connecting wire could be determined with certainty. Before this second method of testing was thought of, it was assumed that near a point where the rails were connected to a pipe, that pipe would be positive to the other system of pipes; also that if, when a car passed a given point, one pipe became highly positive to the other, quickly falling when it had gone by, a connection existed at the point; the same conclusion was drawn if, when cars passed the point, one pipe was always more positive to the others than when cars passed any other point. Though many connections were found by these means, they sometimes led to incorrect results. The confirmatory test referred to depends on the following considerations. If there be a wire at any point, the current entering the pipe will flow in

all four directions if at a crossing, or in both directions if in the middle of a length, and therefore there must be a fall of potential in every direction from the point of connection. This gives a means of determining the direction of the current in any pipe, and if a connection exists the current will reverse in direction at this point.

Along the route of the Metropolitan railway, in which the rails were not generally connected to the pipes, the gas-pipes were usually neutral to the water-pipes along the lower portions of the road, though in other cases considerable variations were found in short distances, the gas-pipes being sometimes positive and sometimes negative to the water-pipes. These variations were due largely to bad conductivity in the rails at certain points, and to difference in the conductivity of the two systems of pipes. One case, in which the rails were not connected across the slot of a cable tramway intersecting them, and which gave rise to some very complicated phenomena, is minutely discussed. At the boundary of the gas-pipe system, the ends of the gas-pipes were positive to the water-pipes, though only slightly so; this the Author ascribes to the dryness of the earth offering a high resistance to the passage of the current, and to the two systems being brought into good contact at many points by their respective service-pipes, with the result that the whole leakage current was fairly distributed between them. Though but little current leaked at any one point, the accumulated leak was considerable, as shown by the water-pipes being positive to the rails just beyond the gas-pipes, and more than half a mile away from the station, the difference of potential increasing rapidly as the station was approached.

It was found that the conductivity of the pipes was determined almost entirely by that of the joints, and that, contrary to supposition, the gas-pipes had a much lower resistance than the water-pipes. The drop of potential across joints varied from $\frac{1}{100}$ volt to $\frac{1}{4}$ volt, reaching $1\frac{1}{3}$ volt in one case, the current being small. The drop in 100 feet of pipe varied from $\frac{1}{80}$ volt to 2 volts, averaging from $\frac{1}{10}$ volt to $\frac{1}{3}$ volt; it was greater after heavy rains, owing probably to increased leakage.

A detailed description of the second series of tests is given, and they are compared with the original series.

The Author points out that the reversals of polarity do not imply danger to the pipe, since the conditions causing them are unfavourable to the passage of current. The general distribution of the current over the pipes tends to reduce the current at any one point below a value that can cause damage, but points of low resistance exist where corrosion takes place, and at these the pipes and rails should be connected together. Wherever the pipes are positive to the rails, the Author advises that they should be connected to them. In the case of several railways in one town, he recommends that their rails should be connected together at various points to diminish leakage, and the resistance of the return.

C. H. W.

On the Electrical Conductivity of Cement and Concrete.

By Dr. St. Lindeck.

(Elektrotechnische Zeitschrift, 1896, p. 180. 2 Figs.)

The Author refers to the leakage of current upon electrical railways where the rails are used as the return circuit, and, after alluding to the damage done to metal pipes laid underground, and also to the disturbance occasioned to electrical laboratories in the neighbourhood, discusses means whereby such leakage may be prevented or materially diminished.

He quotes Dr. Ulbricht and Dr. Kallmann as considering that the rails should be insulated as well as possible from the earth, and cites the fact that the American practice of fixing the rails either upon longitudinal sleepers or cross sleepers, in each case of creosoted wood, appears to give better results than the German practice of laying the rails in concrete.

The earth-current is given by the ratio w_e to w_r, where w_e is the insulation resistance of a unit length of rail from the earth and w_r the resistance of the rail itself. The conductivity of the road-bed is therefore a question of practical interest, and the experiments cited were carried out in the Royal Physical Laboratory.

Cement and Cement Concrete.—Experimental blocks were used, 15·75 inches long by 3·94 inches square, and sheet-iron electrodes with holes in were fixed in these while in a soft state. At least two blocks were used of each kind; and neat cement, as well as various classes of concrete, was tested.

The Author gives details of the apparatus used in the tests and a diagram of connections, and states that an electrometer of the Hallwachs type was used.

The test blocks were made up in July, 1895, and tested two and a half months afterwards. Each pair of blocks was first tested dry, then after being immersed in water for various periods, and lastly after being exposed to a heat of over 212° F.

The results are calculated in the original for a cubic decimetre of the material, and from the data it appears that, while the resistance per cubic foot of the pure cement blocks dry is about 144 ohms, this falls as low as 43 ohms after immersion for twenty-two hours in water, and rises to 820 ohms after being exposed to a heat of 212° F. The greater the admixture of sand or gravel, the higher the resistance becomes, until, with 1 of cement to 7 of gravel, the resistance dry reaches about 1,800 ohms, after immersion falls to 72 ohms, and, after exposure to 212° F., rises to about 2,000,000 ohms for a time. A very large number of results are given in the form of Tables.

It is obvious therefore that such a concrete rail-bed favours the escape of current to earth, especially if the surface of the road consists of asphalt, which prevents the concrete from drying.

The retention of water by the concrete is clearly shown with

the test pieces, made with 1 part of cement to 7 parts of gravel. These gave in an air-dried state a resistance of 5,000 ohms, while after exposure to a heat of 212° F. in an oven the same pieces gave a resistance of from 6 megohms to 7 megohms.

If the highest result obtained for air-dried concrete be taken at about 1,670 ohms per cubic foot, an insulation resistance of about ½ ohm per mile of road is obtained.

Asphalt-Concrete.—Prof. Ulbricht also drew attention in his Paper to the so-called "asphalt-concrete," which has been used for building purposes in Dresden. This consisted of 50 per cent. of broken stone, 20 per cent. of coarse gravel free from loam and sand, 12 per cent. of asphalt, 8 per cent. of coal-tar pitch, and 10 per cent. of German coal-tar. The results obtained were so high that it was doubtful whether the current passed through the material or leaked over the surface.

One cubic decimetre block made with syenite gave when dry an insulation resistance of 280,000 megohms. It was then immersed in water for two hours, and two and a half hours afterwards gave an insulation resistance of 160,000 megohms; while, after six weeks' immersion, it gave 17,000 megohms, and similar results were obtained with the other blocks. The Author therefore believes that, if this asphalt-concrete be used, the leakage of current would be very trifling, and the cost could be kept down by using merely a thin layer of this material over the ordinary concrete. He suggests that a practical test should be made, and if this were done it would decide whether Mr. Gisbert Kapp was right in arguing against the insulation of the rails or not. Prof. Ulbricht was in favour of doing so.

E. R. D.

A Hot-wire Mirror Instrument. By Robert M. Friese.

(Elektrotechnische Zeitschrift, 1895, p. 726. 2 Figs.)

While for the measurement of direct current there are a number of excellent instruments, the same cannot be said for alternate currents.

The Author remarks that only three forms of instrument are of use for direct and alternate currents: (1) those on the dynamometer principle; (2) the electrometer; (3) hot-wire instruments, of which the Cardew is the best-known type. After alluding to the disadvantages of the first two classes, he says that hot-wire instruments may be used without alteration for either direct or alternate currents, and are not sensitive to external influences. The objection to their use is their relative want of sensitiveness, so that considerable energy must be used to obtain exact results; for instance, in order to measure a potential of 2,000 volts, with a Cardew instrument, about 1 HP. must be used.

The Author considers that with certain modifications a hot-wire instrument may be used for laboratory work. The first condition is to find a ratio between the change of length of wire and the electrical magnitude to be measured, and to get the greatest possible sensitiveness. To fulfil the latter condition it is essential that currents should be used which can be employed with ordinary resistance boxes. Although the conditions appear simple, the Author has been employed on the design of a suitable instrument since 1892, when he began to experiment on the subject at the Darmstadt technical school. He then goes into the theoretical requirements which must be fulfilled, and describes his new instrument. The lower part is of cylindrical form provided with an observation hole at the side; there are levelling screws below, and the cover is held by three screws, and into it is fixed a glass tube, inside which is hung the heating wire. To the cover are fixed the moving parts of the apparatus, and a mirror can be brought into position by turning the cover. The lengthening of the wire when heated is changed into a turning movement by means of springs and levers. The lower end of the hot wire is attached to the short arm of a lever carried by the cover, and the wire is kept tight by a spiral spring, while to the long end of the lever is fastened a small mirror, and below it a spring of the spiral shaving form used by Messrs. Ayrton and Perry is fixed to the base of the vessel.

A suitable tension is put on the whole apparatus, which becomes a sort of torsion balance, and the readings are taken by a spot of light on a scale. The movement of the mirror is damped by means of a vane working in paraffin oil.

From a Table of readings it appears that with currents varying from 0·00747 ampere to 0·02730 ampere the constant only varied from 0·00712 to 0·00715.

The instruments are made by Messrs. Edelmann of Munich.

E. R. D.

Electricity Stations as Centres for the Supply of Light and Power and for Railway Working. By Dr. Martin Kallman.

(Elektrotechnische Zeitschrift, 1895, p. 793. 6 Figs.)

This is a Paper read by the Author before the Elektrotechnischer Verein, in which he points out that a change has gradually been taking place in the public supply of electricity. Whereas at first the energy was used solely for the production of light, now the supply of power for motors and for railway working is becoming increasingly important. He takes statistics of seven large stations in towns having populations from 136,000 to 360,000, with an average of 219,000, and the statistics for Berlin, where the Author is city electrician, are given separately.

The stations have been at work for periods varying from one year to three and a half years, with an average of two and a half years. Only one of the seven is worked by a private company, the others being municipal establishments. The stations in Berlin and Vienna are private concerns, and are also alluded to. All the seven stations use direct current, the three-wire system, and accumulators, but in different degrees. Vienna uses principally alternate current.

Taking the average of all the seven stations, if the distributing capacity of the network be taken as the unit, the possible output of the plant is 61 per cent., the actual lamps connected 86 per cent., and the maximum output at any one time 38 per cent.

At the period of greatest output in December the plant was only loaded up to 65 per cent. of its full power in the best station, and to 35 per cent. in the worst, giving an average of 50 per cent. Taking an average for the whole year, that is to say, reckoning the whole time it would be possible for the plant to work, the load factor varies from 4·4 per cent. to 7·1 per cent., or an average of 6 per cent. of the lamps connected. It is, however, obvious that if light alone is supplied a better load factor is difficult to obtain.

As regards revenue from a given network, the longest network connected to any one of the seven stations has 27·9 miles of house-frontage, while the shortest has 5·58 miles. The demand on the network varies from 9 watts to 88 watts per yard of house-frontage with an average of 40·4 watts. A value is thus obtained which may be called the coefficient of lighting density, but it is clear that it will tend to decrease as the distance of the area to be lighted from the business centre of the city becomes greater. The number of houses connected varies from 232 to 592, with an average of 400, and the average number of lamps in use per house is 44. Reckoned per 1,000 inhabitants, the lamps vary from 48 to 160, with an average of 88.

The total cost of the stations under discussion varied from £65,000 to £125,000, with an average cost of £90,000, of which £50,000 was spent on generating plant, and £40,000 on distributing plant. This works out at 14*d.* per watt installed for generating-plant, and 11·16*d.* per watt for distributing-plant. The Author gives curves of the daily and yearly consumption of current, and points out that, as an average, about 15 per cent. of the lamps installed are in use on the days of greatest demand in the winter, while in the height of summer the average is 1·5 per cent. The yearly output of the stations under consideration varied from 270,000 to 470,000 Board of Trade units, with an average of 380,000 units. The sale price varies from 7·8*d.* to 10·8*d.* per unit, while in Berlin it is about 6·84*d.* per unit, with certain discounts. Taking all discounts into account, the average price per unit is 7·56*d.* for all the stations, and an income of £15 to £17 10*s.* per annum can be reckoned per kilowatt installed. The Author then goes into costs of production and gives a great number of figures. The averages appear to be, per kilowatt hour: coal, 0·54*d.* (it is found that 4·4 lbs. of coal

produce one unit, of which 80 per cent. is commercially available); oil, 0·09*d.*; salaries and wages, 1·08*d.*; interest on capital, 2·34*d.*; and office expenses, 2·4*d.* to 3*d.*, making a total of about 6·6*d.* per unit.

The Author gives analyses of a number of other data concerning motor work, and shows some of the results diagramatically.

E. R. D.

A Method of Reducing the Cost of Electric Supply.

By Dr. Rasch.

(Elektrotechnische Zeitschrift, 1895, p. 739. 2 Figs.)

The Author refers to the unsatisfactory financial condition of various central stations for the supply of electric light, due to the very partial use of the generating plant. The highest ordinate of the December curve is a measure of the power of the plant, and upon it depend the costs of plant-administration, as well as salaries, wages and interest on capital.

There is a general desire to increase the load-factor, but the charge of 3*d.* per kilowatt-hour is still too high for motors of considerable size. Lower tariff is needed, and it is useless to require a guarantee that current for power shall not be used during the hours of heaviest demand for light. The Author considers it unfair to inquire the use to which the current is to be put; but suggests that the full rate should be charged for current used between 4 P.M. and 10 P.M. in winter, and between 8 P.M. and 10 P.M. in summer, while a considerably lower tariff should be fixed for all other hours.

He quotes Mr. Gisbert Kapp, who described the system in use at Ipswich, where each consumer has two meters, current passing through one or other according to the hour. In two other places the switching is effected by special clocks. The Author considers the following arrangement much simpler, as it depends upon the property of the watt-hour meter whereby the readings are proportional to the potential at the ends of the volt-coil.

If the instrument is connected in the ordinary way, it gets the full potential on the line; but if a special weak current network be put in, the instruments can be controlled as desired. This network is single-pole only, and may be carried overhead like a telephone-wire, or the test-wires of the network may be employed.

In each house the volt-coil of the meter is connected on to the weak current lead at one end, and on to the ordinary network at the other end; on extended networks it may be necessary to insert secondary calls here and there to keep up the potential of the special network.

A special omnibus bar is provided upon the station switchboard for the volt-meters, and an adjustable resistance is put in circuit.

If, for example, the ordinary potential of supply is 110 volts, and the price in the evening is 9*d.* per unit, and in the day-time 1·8*d.*, then for the period covered by the latter tariff, the volt-coils of all the meters must be worked at 22 volts by means of the special leads.

The Author then goes into detail and explains that the system is applicable also to the three-wire system, and to systems with more wires still. He takes a tariff of 9·6*d.* for the evening, and 1·8*d.* for the rest of the time, and works out numerous examples, by which he attempts to prove that the proposed method would tend to an increase in the load-factor while avoiding the production of a high peak in the curve where the power- and light-services overlapped.

E. R. D.

The Hamburg Electricity Works. By Max Meyer.

(Elektrotechnische Zeitschrift, 1896, p. 168.)

The Author refers to previous articles in which he has given information of a similar kind, and particularly cites Electrotechnische Zeitschrift, 1894, p. 1, in which he arrived at the conclusion that most generating stations could make better incomes by the fuller use of their plant. He now gives details of a recent working period of the Hamburg Electricity Works, the first in Europe to supply electricity for both lighting and street-railway work in such a way as to allow of general deductions being drawn. A complete description of the plant may be found in the Zeitschrift des Vereins deutscher Ingenieure, 1895, pp. 1509–1517. He therefore only gives a few particulars. For lighting there are two sets, each 500 HP., and two accumulator batteries, each for 4,000 lamps; there are three similar sets for street-car work, and a similar one of the same size as a reserve for either. This station cannot be enlarged, but a second one has been constructed by the Electricity Company, late Schuckert & Co., at a distance of 0·94 mile, and 5,000 HP. are installed there. This will leave the first station free for lighting work only.

The Street Car Company serves an area of about 30 square miles. The average total for the last month was 170 motor-cars and 60 tow-cars. The greatest length of line from the centre is 6·82 miles. Certain results are given in the form of tables, and these refer to the last nine months of 1895, and to the normal work of the plant, while that of certain reserve transformers for Sunday loads is not included. Table I shows that whereas in April, 1895, there were 892 customers, 25,330 glow lamps, 1,115 arc lamps, and 62 motors, making 1,717,850 watts on the circuit, these figures had risen in December, 1895, to 1,072, 31,861, 1,342, 130, and 2,213,800 respectively. Table II deals with commercial efficiency. This was in December, 1895, equal to 87·3 per cent. for the accumulators,

loss in leads 14·8 per cent., useful work compared with production 84·3 per cent., maximum daily output 25,632 kilowatt hours. Table III shows a load factor of 56 per cent. when referred to a possible twenty-four hours full load; this is for December, and is obtained by the economical working of the five sets of 5,000 HP. engines, and also by the high efficiency of the batteries. Table IV, which shows costs, is perhaps the most interesting. The results for December, 1895, per kilowatt delivered are as follows: rent, taxes, insurance, &c., 0·0816*d.*; management, salaries, and wages, 0·282*d.*; maintenance, repairs, etc., 0·094*d.*; fuel, 0·35*d.*; oil waste and packing, 0·0384*d.* Total cost, 0·84*d.* This result is also obtained in November, and these are, of course, the most favourable figures, although they are closely followed by those for August, 0·876*d.*, while April is the highest at 1·284*d.* In these calculations receipts by the management for concessions, for reserve fund, and interest are left out of consideration. As according to the police regulations production of smoke is forbidden in the central station in the Poststrasse, expensive fuel has to be employed, and at present English coal costing 19*s.* 1*d.* per ton is used, and gives an evaporation of 9·5 lbs. of water. In the new station it will not be necessary to consume the smoke, so that the work will be carried on more economically. Part of the staff now employed at the first station will also serve for the management of the new station, and this will contain engines of 1,000 HP. to 1,200 HP. each, for which a steam consumption of 12·65 lbs. of steam per I.HP. hour is guaranteed. It is believed that the simple costs of production, as shown in Table V, will descend to about 0·66*d.* or 0·72*d.* per kilowatt hour.

E. R. D.

The "Left Bank" Electric Lighting Station, Paris.

By F. Laffargue.

(L'Industrie Électrique, 1896, p. 165.)

For public electric-light supply purposes, the French metropolis has been divided up into "secteurs," or distinct areas, just as in the case of London with its various companies and local authorities supplying the different districts.

The "secteur," or district, on the south side of Paris, that is, on the left bank of the River Seine, is one of the largest and most important of the areas, though it has only been provided with an electric-light supply at a comparatively recent date. In this article the Author describes in full detail all the plant and equipment.

No very suitable site appears to have been found within the district itself, the power-house being built actually outside Paris altogether, though at a convenient spot so far as water and fuel are concerned, since it is established on the banks of the Seine, on

the Quai d'Issy, beyond the fortifications. This choice of site led naturally to the use of high-pressure alternating current plant, or, conversely, the employment over the scattered area served of a high tension supply rendered it possible to build the power-house outside the city; sub-stations being provided in the area lighted inclusive of the whole southern parts of Paris, between the Jardin des Plantes, the river, the Invalides, and Montparnasse.

The principal feature of interest to be noted, in regard to the generating plant, is the fact that all the engines and dynamos are direct coupled, thus showing a marked change from the usual methods of rope- or belt-driving. When fully equipped the power-house will contain twenty multitubular boilers in four groups of five, each boiler being capable of furnishing 6,000 lbs. of steam per hour at 150 lbs. pressure. The engines are of the horizontal coupled compound condensing type, ten in number, each giving an output of 700 HP. at a speed of 125 revolutions per minute. The cylinders measure 33 inches and 21 inches diameter, with a stroke of 35 inches. Balance piston valves are used for each cylinder, and the regulation of the high-pressure admission valve is effected from a fly-wheel governor, with a cut-off ranging from full to half stroke.

All the engines exhaust into one large trunk (though atmospheric exhausts are also provided for use when necessary), and the exhaust steam is drawn thence through a surface condenser. Condensing water is pumped from the Seine by a large steam centrifugal pump. The condensed steam is filtered and passed into a reservoir, whence it is pumped again for boiler feed.

The alternator is in each case fixed centrally on the engine shaft between the high- and low-pressure cylinders which are connected by a pipe receiver. It is capable of an output equal to 400 kilowatts at 3,000 volts and a periodicity of 42. All these machines are of the Zipernowsky type, with an inner crown of poles forty in number rotating within a ring, with the armature coils on its inner surface. The exciting machines—four in number—are also driven direct by small single-cylinder engines, each indicating 125 HP. and running at 200 revolutions per minute. The machines have six poles, and give each a current of 630 amperes at 110 volts. The engine-cylinders measure 15¾ inches diameter, with a stroke of the same length.

Numerous illustrated particulars are also given at full length, of the switch gear, arrangements of mains and substations, &c.; but these call for no especial mention. The whole of the plant has been supplied by the Schneider works at Creusot.

F. B. L.

The Construction of a Trestle Standard for the Central Telephone Exchange at Havre. By E. Delachanal.

(Le Génie Civil, March 14th, 1896, p. 305.)

The rapid growth of the telephone system at Havre, together with the recent improvements in apparatus, and the introduction of electric tramways (which latter necessitated the abandonment of the "earth" return for the telephones, and the consequent doubling of all the wires), decided the postal and telegraph authorities to install a new central exchange in the building of the "Palais de la Bourse." This building is rectangular, surmounted by a dome at each corner, with a larger one in the middle of each of the longer sides. The ordinary form of standards for the wires on the side roofs would have greatly disfigured the building; and, moreover, there would have been some difficulty in obtaining substantial support for them. It was therefore decided to construct a large trestle between the two larger domes, which while practically invisible from the streets, would still be reached by wires from all sides. There were serious difficulties to be encountered, however, as the centre of the building was occupied by a large hall, 95 feet long by 59 feet wide, covered by a glazed ceiling and glass roof carried, without intermediate columns, on Polonceau trusses, which were unable to take any greater load than that which they already carried.

The requirements in the design of this trestle were:—Even distribution of weight over the foundations of the building and the reduction of this additional weight to a minimum. The structure had also to be sufficiently stiff to allow of all the insulators on one side being connected to wires, while those on the other side were unloaded.

The standard is in the form of a rectangular cage, 52 feet 6 inches long, 26 feet 3 inches high, and 9 feet 10 inches wide; on each of the longer sides are fixed thirty-three horizontal lines of angle bar, $2\frac{3}{8}$ inches by $1\frac{9}{16}$ inch by $\frac{1}{4}$ inch, spaced $9\frac{3}{4}$ inches apart. Each angle bar carries sixty-four insulators, also spaced $9\frac{3}{4}$ inches apart; and with those which can be attached to the ends, the cage can take a total number of 4,400 insulators. The insulators themselves are specially designed, so as to throw no torsional strain on the angle bars to which they are attached.

The bottom of this cage is 9 feet 10 inches above the glass roof of the building, and the top of it 111 feet 6 inches from the ground. It is carried by four hip beams at the corners and two intermediate "A" trusses. These hips and trusses are tied together along the upper line of the walls on which they rest, and again at about half their height, so as to take up all horizontal thrust except that due to uneven loading of the telephone wires; while the hips have a very good abutment on the cross-walls at the corners of the hall. The cage itself is covered in with glass,

and access is given to it by means of stairs from one of the domes.

The erection of this standard was also no easy matter. The "Bourse de Commerce" was held in the central hall, and no interruption of its business was allowed; while, as already stated, no additional weight, even temporarily, could be put on the trusses of the roof. An overhanging crane was therefore constructed, standing in a yard at one side of the hall, and travelling on a curved path which enabled it to command the whole of the area to be dealt with, while its travel was very short. The jib of this crane was pivoted at its centre on a truck running on overhead rails, and an attachment to its tail enabled it to be raised or lowered as required. The erection of the temporary work occupied from the 19th of June, 1895, till the 22nd of July, that of the standard itself from the 23rd of July to the 23rd of August, and the removal of the temporary work occupied five days more. The whole of the metal work is of light lattice construction, the gross additional weight on the building being about 60 tons, and the cost complete about £1,400.

The Paper is accompanied by three views of the work in different stages of completion and a full-page plate of explanatory details.

R. B. M.

Telephone Construction in the Rocky Mountains.

By J. W. Dickerson.

(The Electrical World, 1896, p. 312.)

The Author describes the chief characteristics and difficulties met with in constructing cross-country telephone lines for the Colorado telephone system. Nearly half the total length of pole-line is in highly mountainous country, and the most recently equipped section—that from Leadville to Aspen—practically crosses the main divide at a height of not less than 12,000 feet in its course of about 48 miles. The poles are set ordinarily about forty-two to the mile, increasing to seventy-five at curves and sharp turns. In crossing wooded country, the timber is cleared away on each side of the line for a width of 200 feet, so that falling trees or branches may not break the wires. No little difficulty was experienced in rocky soil in digging the pole-holes, 5 feet deep, even with the use of blasting-powder. At the extreme summit of the divide, pole-construction was abandoned, and a cable used for the circuits, buried in a two-foot trench, for a distance of 1½ mile. Previous experience on another section (where poles placed 15 feet apart failed to sustain a No. 6 wire in winter when sleet had accumulated on it) showed the advisability of putting the wires underground. No little difficulty is found in maintaining the lines during winter; the lines-men travel on snow-shoes, and if stormbound

have to find refuge in some deserted cabin along the route. Moreover, they cannot at such high altitudes climb more than two or three poles consecutively without a long period of rest.

Illustrations are appended showing a map and views of the route.

F. B. L.

The Regulation of Electrical Motor-Cars. By E. G. FISCHINGER.

(Elektrotechnische Zeitschrift, 1896, p. 206. 22 Figs.)

This is an article dealing generally with the design of the whole of the mechanism for regulating the speed and direction of electric motor-cars; it also deals with the use of the electric brake upon such cars.

The Author first describes, with the aid of diagrams of connections, three different methods of altering the strength of the field in the motor. The first is a method used by Messrs. Siemens and Halske, and by the Union Electricitäts Gesellschaft; the second is a system brought out a year ago by the Author at the works of the A. G. Elektricitätswerke, late O. L. Kummer and Co., but not put into practical use, as the third system was found better.

The second system resembles that of Mr. Sprague, but the Author is careful to point out wherein it differs from that system, and he claims advantages for his own. He considers the Sprague arrangement good if the cars are to run only on level roads, but not if they are to ascend gradients, and he believes his own system to be more economical than the first system alluded to.

The third system was designed by the Author to fulfil the conditions that grades should be ascended at a lower speed than that used on the level without putting back the regulator. For this it was necessary to have a magnetic field, the strength of which could be increased, and the Author gives curves showing the results obtained; the abscissas denote speeds or revolutions per minute, and the ordinates the current in amperes used with an electromotive force of 460 volts between the terminals.

One of the curves shows, for example, that with this motor the speed of the car can be altered from 10 miles to 15 miles per hour, using the same current of 20 amperes, solely by weakening the field; this allows the speed to be raised outside the town limits to the extent of 50 per cent., which is permitted by the authorities.

The inserted resistances are only necessary at starting, and then merely until the motor is able to produce a back electromotive force sufficiently great. About 40 amperes are usually employed on level ground, and a speed of about 7 miles per hour is obtained. The Author points out how small is the loss by the use of the resistance coils, but the use of contact steps is objectionable; he has therefore designed a water resistance.

The mechanical brake and the switch-controlling gear are on the

same piece of apparatus; it is therefore impossible to have a spring break on the contacts.

Before describing the special parts of the apparatus the Author shows by diagrams how the working of the brakes and the controlling gear depend upon each other, and deals with the matter at great length both for cars with one motor, and for those with two motors. The cars can also be stopped by short-circuiting, the motors thus obtaining a powerful braking action, and the Author considers it all that can be desired; if neither accumulators nor tow-cars are used, the action does not cause sparking at the commutator. In the summer of 1894 he carried out experiments with a motor car fitted with two motors on dry, clean rails, and when the car was running at a speed of 13·64 miles an hour, it was stopped in a space of from 23 feet to 26 feet. This result, however, was not attained with the heavy accumulator cars and trailers used in Dresden, and it was found necessary to provide the empty axle and the axles of the trailer with magnetic brakes shown in detail in the original.

This brake consists of a cup-shaped portion loose on the axle, and prevented from turning by being fixed to the framework of the vehicle; this portion carries the magnetising coil and has a rubbing ring separately fixed upon it. The other part acts as armature, is also cup-shaped, and carries a ring of separately fixed rubbing pieces. It is normally kept free from the electro-magnet part by means of spiral springs. From experiments it has been proved that 20 watts are sufficient to draw up the brake from a distance of $\frac{1}{4}$ inch to $\frac{5}{16}$ inch, but as several hundred watts are available, satisfactory working can be relied upon. The Author describes a type of fluid-resistance box which has given very satisfactory results during the last eighteen months, and describes and fully illustrates the apparatus used for altering the speed and direction of movement of the car.

It appears that the car motors are made in four sizes by the company with which he is connected, viz., 8, 15, 20, and 30 HP.; one of these motors is illustrated in the original, and it is claimed that the output is very great for the weight used.

E. R. D.

The Substitution of Electricity for Steam in Railway Practice.

By Louis Duncan.

(Transactions of the American Institute of Electrical Engineers, 1895, p. 374.)

In order that it may pay in practice to alter the motive power of a railway, it is necessary that the receipts must be increased or the expenses diminished by an amount rather greater than the interest on the first cost of the change.

The Author quotes statistics to show that the tendency is to

run shorter and more frequent trains for passenger traffic, while for goods traffic the opposite practice of having heavy trains with a single locomotive has grown up, the weight per train-mile having more than doubled between 1870 and 1890. For the former class of traffic electricity is eminently suitable, since the conditions imply a distributed load with a maximum demand not greatly exceeding the average load, the cost of generating plant and mains being therefore low; while with steam, the increase in number of locomotives leads to much greater expense, it being stated that doubling the number of engines increases the working cost 50 per cent. With goods traffic the conditions are exactly reversed, a single locomotive of large power being economical, while the cost of electric traction is great, the irregular distribution due to the few and heavy trains entailing a larger capacity for the mains and, if several generating stations are employed, for the stations, and even if only one station working at high tension is used, although by this means its capacity need not be augmented, that of the transforming devices must be increased. The Author does not consider it possible to devise any more economical method of dealing with goods traffic, and the difficulty of introducing a change would be greatly enhanced by the large amount of through-traffic which, as in a case cited, may amount to 46 per cent. of the total goods mileage. This class of traffic is of great importance, since the revenue from it on all lines in the United States is from two and a half to three times as great as that from passenger traffic.

Since, in the Author's opinion, it would not pay on trunk-lines to make any change as regards goods traffic, he considers the question of utilizing partly steam and partly electric traction, and details his reasons for arriving at the following conclusions. For a through-line with two tracks, having through as well as local traffic, it is not advisable to employ electricity on the main lines. When there are four tracks, if the line connects two cities which are termini for all passenger traffic, by equipping all tracks the express service could be run at short intervals on two, while goods and local trains could run on the other two, the local trains being electrically propelled. When, however, there are a large number of through-trucks from other lines the conditions are not so favourable for the express service. For branch lines the question depends on the length and frequency of service; if the line is short and there is considerable passenger- but little goods-traffic electricity is preferable, but not otherwise.

The Author draws attention to the great danger to railway companies of the local traffic being diverted to electric tramways running between the same points as the steam lines, the tramways having the important advantage that they traverse the city and extend in all directions in the suburbs. On some branch lines he thinks it would be advisable to use single electric cars running on the steam lines between towns and on the tram lines locally, a number of motors being used to allow of their grouping being

varied according to the permissible speed and the pressure of the supply. As regards the particular electric system to be adopted, he thinks that trolley-lines with continuous currents the most suitable and reliable, different pressures being used in towns and on the lines between them. For very long lines the working current should still be continuous, but it might be supplied from rotary transformer sub-stations, fed by alternating currents. As an alternative, a two- or three-phase system, with rotary field motors on the cars, might be adopted, in which case he suggests that different periodicities should be used in towns and on the lines.

The Author passes on to the case of new lines built especially for electrical working; these are generally used almost exclusively for passenger traffic, and the most favourable conditions for this system, therefore, exist. Referring to the New York underground line, the Author thinks that about 150 trains, each with one motor car hauling five ordinary cars, will be required for the local service, and twenty-five trains, each with one motor car and four trailers, for the express. Direct current, distributed on the three-wire system, would be the best, the chief reasons being that with four motors on the car, all necessary speeds could be attained economically by varying their grouping, and a large amount of the energy lost in stopping could be restored to the line; this is of great importance in the case of the local trains, since the amount of energy that has to be got rid of in stopping so frequently is very large, and the Author thinks that with motors of ordinary efficiency, about 45 per cent. of the energy can be returned. He advocates the use of batteries, to give a uniform load to the generating station, the capacity of which may in this way be reduced almost to one-half that which would be necessary were the energy not returned. The objections to the use of alternating current for lines like the one in question, are the impossibility of restoring the energy and the difficulty of varying the speed. For elevated roads the same system would be best; existing structures would require the use of shorter trains.

A railway scheme of the Baltimore and Columbia Railway Company is referred to, in which ordinary speeds are to be used in the city, and speeds of 60 miles per hour outside it, and a good many problems will have to be solved, among them that of providing an underground conduit in the District of Columbia, trolley-lines not being allowed therein.

The Author concludes with a description of the Belt line tunnel, which runs for a distance of 1¼ mile beneath the city of Baltimore, the line continuing to the outskirts of the town through cuttings and short tunnels; the gradient is 1 in 125 in the greater part of the tunnel, and ½ mile beyond it it is 1 in 67. The difficulty of ventilation has led to the provision of electric locomotives to haul the trains, steam-engines included, over this portion of the line. There will be three of these locomotives, but two will ordinarily suffice; they will run over about 3 miles of line, and will assist the

goods steam locomotives to haul the trains up the incline outside the tunnel. The current is conveyed to the motors by means of an overhead line, which is placed between the tracks at a height of 22 feet from the top of the rail outside the tunnel and 17 feet within it, there being insufficient headroom for the ordinary arrangement. The conductor is formed of an iron trough, made up of two Z-bars, riveted to a cover-plate 12 inches wide, leaving a slot 1 inch wide between the bars; they are in 30-foot lengths, riveted and bonded together. The trough is carried by channel bars, hung from expansion bolts fixed in the top of the tunnel, and from catenaries, supported by iron columns 150 feet apart outside. Copper cables are used as feeders, and one serves to increase the conductivity of the return circuit. Contact is made with the trough by a brass shoe travelling within it. Current is supplied from generators giving 600 volts at no load and 700 volts at full load, coupled direct to 750 HP. Allis-Corliss engines. The locomotives have eight driving-wheels, and weigh 95 tons each.

C. H. W.

Electric Traction by Accumulators in Paris. By G. Pellissier.

(L'Éclairage Électrique, vol. vi., 1896, p. 49.)

The Author commences his description of the past and present attempts in accumulator traction in Paris, by a short review of the present attainments in accumulator manufacture. All makes of accumulators when new give approximately the same results when the output per pound of active material is considered; but after a time more or less distant the period of faults commences. Disintegration of the framework or of the paste weakens by degrees the mechanical strength of the cell. Accidents then become numerous and the cost of repairs rises quickly. Hence the cost of accumulator traction, which on the first trials gives favourable financial results, leads in time to deficits. The first attempt at electric traction by accumulators in Paris was organised by Mr. Raffard in May 1881. A tram-car holding fifty passengers was equipped with old Planté type cells. The small cylindrical plates forming one cell weighed 17½ lbs., and 16 such cells were carried in each wooden box. The whole battery was capable of giving 40 amperes and 120 volts. The motor used was made by Siemens, and drove the car through a double reduction belt-gear. The first trials were satisfactory, a speed of 5 miles per hour being attained, but the batteries proved to be unfit for continuous work, and hence the attempt was abandoned. The same fate attended a further trial in 1883, with a vehicle using 6,600 lbs. weight of Faure-Sellon-Volkmar accumulators. The vehicle was, however, run for five months. In the same year Mr. E. Reynier also experimented with accumulator traction, and invented the series-

parallel method of coupling up accumulators for different speeds. The next practical attempt was made in 1892, when the Société du Travail Électrique des Métaux equipped the line from Paris to Saint Denis. The accumulator cars on this line and on two adjacent lines worked by the same company have been run up to the present time. The Author proceeds to describe in full detail the charging station and arrangements, and also the accumulator cars used on these three lines. The weights of the cars for fifty passengers are as follows:—

	Lbs.
The car alone	16,500
The battery of accumulators	6,600
The passengers	7,700
Total	30,800

The cars are of the radial type, which gives facilities for passing round curves. There are 108 cells of 11 plates each in the battery, which are arranged in 12 wood boxes, 6 on each side of the car. The batteries are removed to be charged, and the limited space in the shed necessitated the use of small trucks, to convey the cells to a common charging platform. It is claimed, however, that the empty batteries could be withdrawn and new ones inserted in the car in six minutes. A car when recharged is able to run about 37 miles on the Broca type of rail, and twice that distance on the Vignoles rails.

The Author proceeds to give the number of calculations as to the efficiencies of the various steps between the power of the engines and the power given out by the motor. These calculations are followed by some statistics as to the consumption of coal and oil per car-mile.

The following are the mean results obtained:—

	Cost per Car-Mile in Pence.
Handling accumulators	0·92
Upkeep of accumulators	1·54
Upkeep of motors and trucks	0·78
Motive power	2·77
Wages and superintendence	1·23
Total	7·24

This price is high compared with electric traction on the overhead system, at which the cost comes out at 4·62*d.* per car-mile in Paris. With the experience gained on these cars, new ones were designed which are more convenient in every way. The chief new feature is the employment of the motors as an electric brake when the car is to be stopped. The Author claims that the current so returned to the batteries is appreciable, and gives a series of curves taken for practice, which shows that on a typical journey of total output of 625 ampere hours some 216 ampere hours were returned to the battery.

With the new car and accumulators the working expenses are stated to be as follows:—

	Cost per Car-Mile in Pence.
Upkeep and handling accumulators	1·54
Motive power	2·00
Upkeep of motors and cars	0·46
Wages and superintendence	1·23
Total . . .	5·23

The article is illustrated by 14 figures.

R. W. W.

Electric Tramway and Lighting Station, Baden, near Vienna.

By Oscar Bühring.

(Elektrotechnische Zeitschrift, 1895, p. 525.)

The question of combined electric supply from one power-station for both lighting and traction purposes has become increasingly important of late, and in this article the Author gives particulars of an installation of this kind which, though comparatively small, has points of great interest.

The tramway lines operated are three in number, with lengths respectively of 2¼, ½, and 3¼ miles; the two former are converted horse-lines, the latter quite new. The mode of working adopted is the usual overhead trolley-wire plan, with wood and iron poles, and span wires fastened across the streets, where necessary or advisable, to ornamental iron rosettes on the buildings on each side. The greatest care is taken throughout to keep the overhead structure unobtrusive, in view of the high-class districts through which the lines pass.

Twelve motor-cars are employed, ten of these accommodating twenty-eight passengers, and the other two twenty-five each. Their weight is 6 tons each in working order, and the leading over-all dimensions—length, 19 feet; width, 7 feet; height, 10 feet. The horse-cars formerly used are employed as trail-cars, each accommodating eighteen passengers seated and sixteen standing. Each motor-car is provided with two 8-HP. motors, geared in the usual way to the car-axles. All regulation of speed and direction of car-movement is effected by a single controller handle at each end of the car, with of course the ordinary mechanical brake in addition. The maximum average speed attained is 16 miles per hour outside the town, and the service proves sufficiently popular to carry an average of five passengers per car-mile.

The power-house occupies the sheds formerly used as a depôt for horse-traction. Although not conveniently situated so far as the network is concerned, it was considered that the cost of land and

buildings better situated would more than counterbalance this disadvantage. The area covered is rectangular in shape, 150 feet by 40 feet, and gives space for an output of 300 HP., four units each of 50 to 80 HP. being at present installed. The boilers employed are of a combined type—multitubular and Cornish, with corrugated main flue, and each with a heating-surface of 861 square feet. The engines are horizontal compound with jet condensers, working at 112 lbs. steam-pressure and at a normal speed of 180 revolutions per minute. They are coupled by belts to four-pole dynamos running at 600 revolutions per minute, and generating current at the usual pressure of 550 volts at full load. The current is used direct from the dynamos for the tramway service, but is transformed for lighting purposes, there being a sub-station about 1¼ mile from the power-house. Here are installed two continuous current transformers reducing the pressure to 220 volts for a three-wire system of distributing mains, and also a battery of accumulators, put in parallel, consisting of 136 cells, 68 for each half of the three-wire system. This battery has a capacity of 830 ampere-hours, and together with either transformer is equal to a load of 1,800 lamps of 16 candle-power each, burning simultaneously.

At present lamps equivalent to 2,500 of 16 candle-power each are connected up, also 52 arc-lamps of 6 amperes each, employed in street lighting. The rate charged to consumers for current used in private lighting is 8*d.* per unit.

The article is illustrated by thirteen engravings and diagrams.

F. B. L.

Electric Power in Factories and Mills.

By F. B. Crocker, V. M. Benedikt and A. F. Ormsbee.

(Transactions of the American Institute of Electrical Engineers, 1895, p. 404.)

The Authors point out that although the adoption of any system of power distribution depends primarily upon the cost, yet if the difference in cost between two systems is not very great, the question of convenience has great weight. They enumerate the following advantages of the use of electric motors instead of belts and shafting: (i) facility for the use of travelling-cranes, owing to increased head-room; (ii) ease of moving tools from place to place; (iii) saving due to being able to run one tool by itself; (iv) the absence of any absorption of power when a tool is stopped; (v) the avoidance of the drip of oil from over-head shafting; (vi) the ability to place tools at any point, irrespective of distance; (vii) the tools need not be placed parallel to one another; (viii) a wider range of speed is possible; (ix) increased safety in case of overload, a fuse merely blowing instead of a belt

flying off. The Authors believe that in time electric driving will displace the older system.

After referring to what has been done, full particulars are given of a number of determinations of the power taken by various tools in actual practice; these are summarised in the table.

The power was determined by measuring the current taken by the motor, readings being taken every few seconds, the interval between the readings depending on the nature of the tool and the work it was doing. The pressure was 110 volts, and did not vary more than 1 or 2 per cent.

The Authors call attention to the fact that the power taken by the several tools had been largely over-estimated in the greater number of cases, the motor being only half loaded. As regards the extent to which shafting should be done away with, they are of opinion that for large tools it is best to use a separate motor, while for small tools it is preferable to arrange them in groups, with a motor for each group.

The use of electric distribution of power in New England cotton-mills has, it is stated, fairly begun, many having certain sections driven electrically, although none are yet entirely so worked. A short account is given of the plant at a dye-works in Providence, R.I., where motors developing about 100 HP. are at work, the most important being one driving a centrifugal pump taking 30 HP.; also of that at a calico-printing works at Pawtucket, R.I., the chief interest of which lies in the difficulty that had to be met in causing the motor to run at different speeds, and to keep running uniformly at any one of them under a variable load, a modification of the Ward Leonard system of regulation being employed for this purpose; and at Baltic and Taftville, between which places there is a transmission of 500 kilowatts by means of alternating currents, one of the two motors driving 1,200 looms, taking about 155 HP., and the other 500 looms, and the generators for the Norwich Electric Railway Company.

The Authors are of opinion that, though in many cases the first cost of fitting up the necessary plant for electric driving is high, yet in the case of very long or scattered buildings, or those with many storeys, it would be actually cheaper, one item of saving being the diminished strength required in ceilings or roofs. The loss of power in transmission is less with the electrical method, in spite of the double conversion, and very great saving is effected through there being no waste when a tool is stopped, the time of stoppage being at least 25 per cent. of the nominal working hours, and as much as 50 to 75 per cent. in the case of large or special tools. Great economy is effected when motors displace small separate engines scattered about a works. The greater convenience and facility for starting, stopping and speeding up lead to an increased output—and in the case of the Pawtucket calico-printing works referred to, this is stated to have been as much as 25 per cent., while the quantity of inferior product produced was

greatly diminished. As an instance of the great flexibility of the electric system, the Authors mention a case in which a factory was almost wholly destroyed by fire, and yet within two days a few uninjured tools in a distant part of the building were got to work by means of motors.

The speed is varied in most cases by inserting a resistance in the armature circuit of the motor, which is shunt wound, but when the variation has to be between wide limits, a series motor, controlled by a resistance, as on electric railways, may be preferable. Other methods of regulation referred to are the Ward Leonard and the "boost and retard" systems.

C. H. W.

Three-Phase Alternating Plant of the Fives-Lille Company.

By PAUL GIRAULT.

(L'Industrie Électrique, 1896, p. 144.)

In the article from which these particulars are taken, the Author enters into a long account of the three-phase alternating plant (generators, motors and transformers) designed and manufactured by the well-known Fives-Lille Company. The generators are of two chief types, one with rotating armature, more particularly designed for comparatively low pressures, whilst in the second type a mass of iron alone rotates between the pole-pieces. There are no striking novelties in the former; an illustration is given of one machine capable of yielding 230 amperes at 115 volts in each circuit (connected star fashion) at a speed of 430 revolutions. The field is of cast iron with 14 poles, so that the machine gives a frequency of 50. The armature-core is built up in the ordinary way of thin iron disks separated by paper. For machines of greater output than 80 kilowatts, the field carcase is made of very soft cast steel.

The second class of generator is illustrated by a machine giving 140 kilowatts at an effective pressure of 2,500 volts, running at 180 revolutions. A large ring-shaped inductor-frame is used, made of laminated soft steel, of trough section thus ⊃; the exciting coil lies at the bottom of the recess, and the crown of iron poles (supported on the engine fly-wheel) rotates between the sides of the trough.

The three-phase motors vary from one another only in regard to the armature windings (whether ring or drum), and also to the conditions of starting. Their efficiencies ("industrial") range from 70 per cent. to 90 per cent. for powers varying from ½ HP. to 30 HP. The frequency is 50, and the circuits are grouped in star fashion. Motors above 3 HP. output are usually provided with a variable liquid starting resistance. A large starting-couple may be obtained within limits by putting resistances into the armature-

circuit, involving, however, the use of collecting-rings and brushes, whether the armature or field rotate. For certain purposes, as for example, the direct driving of hydro-extractors or centrifugal-machines in sugar refineries, rubbing contacts are not advisable; and the Fives-Lille Company therefore build special motors having a relatively large resistance in the armature-circuit. In operating machinery of this kind, the difficulty of attaining full speed at full load within a short time (*i.e.*, one or two minutes) is thus met; the further difficulty in some types of beginning to run at one speed and after a while doubling the velocity (as in the Hubner centrifugal), is met by using two generators with different frequencies, one of 50 and one of 25. A number of illustrations accompany the article.

F. B. L.

Electric Equipment of the Escher Wyss Factories at Zurich.

By P. Gasnier.

(L'Industrie Électrique, 1896, p. 120.)

The Author deals with the electric equipment of the factories in its relation to the main supply derived from the electricity station at Zufikon-Bremgarten.

Two large three-phase alternating transformers, each of 200 kilowatts capacity, are employed to reduce the high-tension supply, and two low-tension steam-alternators are installed as a reserve or stand-by in case the main supply should by any possibility fail. Two six-pole continuous-current generators also serve for lighting — this generating plant being all driven by a large triple-expansion steam-engine. The alternators run at 250 revolutions per minute; they are of the fixed armature Oerlikon type, each with an exciter mounted on the same spindle. The poles are 24 in number, and the turns in the armature 144. The continuous-current machines have an output of 500 amperes each at 120 volts, and 480 revolutions per minute. There are in all about 130 arc lights and 800 glow-lamps in the works. The lighting is effected on the three-wire system, but an arrangement is provided for running in ordinary two-wire parallel at times of light load, so that only one machine need be employed. The alternators may be run in parallel with the transformers if required.

The motors employed in the works vary from 1 HP. to 100 HP. For operating the various machine-tools, &c., there are in all twenty-four motors, with a total of 490 HP.

For operating the cranes and lifting appliances generally no less than fifty-nine motors are in use, having a total of 327 HP. These range from 1 HP. to 18 HP. each, there being five of the latter, two of 12 HP., eight of 9 HP., seven of 6 HP., six of 4½ HP., fifteen of 3 HP., eight of 2 HP. and the same number of 1 HP.

and 1½ HP. The 20 HP. and 100 HP. motors have ten poles, and run at 575 revolutions; the 6, 9, 18, 24 and 36 HP. motors are all six-pole machines running at 970 revolutions; the smaller ones, ranging up to 4½ HP., have four poles, and run at 1,450 revolutions. Some of the 4½ HP. machines are of lower speed, having eight poles, and running at 725 revolutions. They may all be safely overloaded 20 per cent., and the speed, when running light and at full load, does not vary more than 3 per cent. Up to 6 HP. the armatures are of squirrel-cage type; above that output they are drum-wound. Motors below 9 HP. are started without resistances; above that output a water-resistance is used in the field-magnet circuit. The lifting-crane motors are also started by means of a rheostat.

There are twenty-four overhead travelling cranes operated by electricity—five of 20 tons capacity, ten of 10 tons and nine of 5 tons. Worm-gearing is employed for speed-reduction, and separate motors are used for the three different movements, the speeds being respectively 65 feet per minute for the longitudinal travel, 32 feet 6 inches per minute for the traverse, and from 2 feet 8 inches to 5 feet per minute for the lift, the latter speed being variable according to the weights lifted.

F. B. L.

Siemens and Halske's Safety-starter for Lifts.

By Hugo Langner.

(Elektrotechnische Zeitschrift, 1895, p. 663. 4 Figs.)

One of the special features of lifting-apparatus is that the motors are very frequently stopped, and started, and reversed. In the case of passenger-lifts, the motor is usually out of sight of the attendant and is controlled by a rope. Such motors are therefore in more unfavourable conditions than ordinary motors, which are started and stopped perhaps only once a day.

Special apparatus is needed, and electrical firms have long been paying attention to the subject. The most usual form of starter is that in which the sliding contact of the resistance coil moves forward from its central position as soon as the steering-rope is pulled and the speed of motion can be regulated by a kind of brake.

In order to lessen the bad effects caused by sparking at starting and stopping, special switches are often used.[1]

Messrs. Siemens and Halske have brought out a different arrangement which has been found quite satisfactory.

Metal contacts being much injured by sparking, it was decided to use carbon, but as this material is not suitable for rubbing

[1] Elektrotechnische Zeitschrift, 1895, p. 450.

2 L 2

contacts another arrangement had to be adopted. In the original design the ends of spiral resistance coils were connected to a row of cylindrical carbons, insulated from each other and fixed to the base of the apparatus.

Above the fixed carbons was a row of movable carbons, each provided with a spiral spring, and the whole row was fixed to a cross-bar, which could be raised or lowered; when lowered the upper carbons made contact with the lower contacts, and the action of lowering cut out one resistance coil after another. The resistance and carbon apparatus were in series with the armature.

Neither sparking at opening or closing, nor the glow caused by the passage of heavy currents, produced much wear, and fewer carbons than metal contacts were needed. The large number of metal contacts usually employed is caused by a desire to protect from fire rather than to avoid sudden fluctuations of current. With the usual type of 7 HP. motors, four pairs of carbons are found sufficient. The first type was controlled by the usual lift-gear; this moved the starting-switch from its mid-position, causing current to flow in the field-magnets in one direction, and in the armature according to the desired direction of motion. The cross-bar sank by its own weight, its motion being controlled by an air dash-pot; this corresponded to the ordinary gear, but soon gave place to the following improved type.

The single coils of the starting resistance must be cut out at the same rate as the counter electromotive force of the motor increases with the speed. The positions of the carbons should therefore be directly controlled by the speed, and this is attained by the use of a centrifugal governor driven off the motor shaft and actuating the cross-bar carrying the carbons.

The Author states that the action of the apparatus is noticeable neither in the lift nor upon the supply service.

The gear also acts as a safety arrangement in case of accident. If the car stops for any reason the whole of the resistance is at once put into circuit, and this is much better than a fuse, as the latter must be replaced when melted.

The apparatus is shown in the original Paper arranged in different ways to suit local circumstances.

The Author states that it works well, and he refers to six goods lifts with 7 HP. motors in a granary at Wilhelminaquai, Rotterdam, working with 440 volts off the town supply. Heavier apparatus are made with six to nine pairs of carbons, and these are suitable for motors up to 30 HP. Two passenger lifts have recently been put into the City Hall, Berlin, and these are worked with 210 volts. The apparatus is suitable for rotary currents also; and electrical supply companies must be interested in its use as it lessens fluctuations on the supply circuits.

E. R. D.

Observations on the Electric Charges in Thunder-clouds.

By A. NODON.

(L'Électricien, 1896, p. 7.)

The Author summarises the conclusions which can be drawn from experiments made at the Physical Laboratories at Sorbonne on the above subject.

In the experiments a perfectly insulated metallic disk was exposed in the open air and connected to a Mascart electrometer. The Author refers to the Comptes Rendus of the Académie des Sciences for August 5th, 1889, for the details of the apparatus. The following are the conclusions after experiment on a series of storms in June, 1895:—

1. The relative potential indicated by the electrometer during the interval between two lightning flashes attains a certain maximum which is invariable during the whole storm.

2. This maximum potential is independent of the distance between the point of observation and the point where the lightning struck the earth.

3. These facts enable the observer to predict the exact moment at which a flash of lightning would occur, for as soon as the maximum potential referred to above is shown on the electrometer the flash is observed.

The Author remarks that a thunder-cloud would seem to be a sufficiently good conducting mass as to be considered as presenting an equipotential surface on which the electric equilibrium is quickly re-established after a partial discharge.

R. W. W.

A Contribution to the Solution of the Fire-damp Question.

By L. JAROLIMEK.

(Berg- und Hüttenmännisches Jahrbuch der k. k. Bergakademien, 1895, p. 351.)

In an exhaustive memoir covering fifty-six pages the Author gives the results of investigations and experiments, extending over a number of years, made with a view to obviate the dangers of blasting in fiery mines. In the new method of blasting he has devised, a quicklime cartridge and a dynamite cartridge are connected, and the compound cartridge is enclosed in a bag of cotton woven like a wick. A detonator embedded in the dynamite is exploded either by means of the evolution of heat or by means of the increase in volume setting in action a friction-ignition apparatus.[1] Experiments were made in a lamp-testing apparatus

[1] Minutes of Proceedings Inst. C.E., vol. cxxiv. p. 501.

containing 7·5 per cent. of fire-damp, as well as in a gallery containing 6·8 per cent. of fire-damp and coal-dust kept in motion, and in neither case did the explosion of the cartridge fire the gases or the coal-dust, the flame being confined to the interior of the cartridge, and being impeded both by the slaked lime and by the water in the bore-hole at its upper end. The practical conclusion from these tests is that none of the shots, in the mixtures of air with fire-damp and coal-dust in what has been shown by experience to be the most dangerous proportions, ignited the gases, although the shots were fired exclusively with ordinary dynamite and not with safety explosives, and although the bore-holes were overcharged, and in some cases only a very small quantity of water was used. The Ostrau Special Committee on Fire-damp carefully tested the Author's method of blasting, and have reported that it is calculated to render the ignition of explosives in bore-holes in fiery mines absolutely free from danger.[1]

B. H. B.

Underground Temperatures at Great Depths.

By Alexander Agassiz.

(American Journal of Science, vol. l., 1895, p. 503.)

At the Calumet and Hecla copper mine, Lake Superior, which has now attained a vertical depth of 4,712 feet, rock-temperature observations have been made at various depths, with the aid of slow registering Negretti and Zambra thermometers placed in bore-holes drilled slightly upwards to a depth of 10 feet, and plugged with wood and clay. In these holes the thermometers were left from one to three months. The highest rock-temperature obtained at a depth of 4,580 feet was 79° F., whilst the rock-temperature at a depth of 105 feet was 59° F. The difference of temperature in the column of 4,475 feet of rock is thus 20°, the increase averaging 1° for 223·7 feet. The result is very different from any recorded observations, Lord Kelvin giving 1° for 51 feet, and the temperature observations of the St. Gothard tunnel giving 1° for 60 feet. The average annual temperature of the air at the Calumet and Hecla mine is 48° F., and that of the air at the bottom of the shaft is 72° F.

B. H. B.

---

[1] See also Report of the Royal Commission on Explosions from Coal-Dust in Mines, London, 1891–94.

Refractory Gold Ores of Queensland. By E. A. Weinberg.

(Annual Report of the Under Secretary for Mines, Brisbane, 1895, p. 33.[1])

Refractory ores, which do not yield their gold on treatment by amalgamation on copper plates, are of general occurrence in Queensland, but it is only of late years that a systematic method of dealing with them has been adopted. For convenience' sake they may be classified into (1) refractory gold ores, massive, carrying 40 per cent. and upwards of pyrites or other sulphide; (2) concentrates of pyrites and other base metal sulphide with 80 per cent. and upwards of mineral; (3) tailings; (4) comparatively rich ores with very little sulphide (the Mount Morgan ore); and (5) argentiferous and exceptional ores.

Although the Queensland mills are stamping annually some 400,000 tons of quartz, which may be estimated to yield 2½ per cent. of mineral contents, the production of clean concentrates not carrying more than 5 per cent. to 20 per cent. of sand, falls much below 1,000 tons a year. It is evident that these results would be greatly improved if more attention was paid to concentrating appliances.

At the present time Queensland is well provided with metallurgical works, which are fully able to deal with the refractory gold ores of the colony. There are large chlorination works at Mount Morgan, and others on a smaller scale at Charters Towers and Ravenswood. There are general smelting works at Aldershot, and cyanide works at Charters Towers, Croydon, and Georgetown. At the Mount Morgan Chlorination Works, vats holding about 25 tons of charge have replaced the barrels and smaller vats. The chlorine is now being applied there as chlorine water. In that way the consumption of the solvent can be better controlled. The use of chloride of lime and sulphuric acid has been superseded again by manganese, salt, and sulphuric acid, and by the installation of chlorine stills, towers, and solution tanks. In 1894 these works treated 65,076 tons, assaying 1·66 oz. of gold per ton, the extraction being within a small fraction of 95 per cent. of the assay value of the ore. The actual cost of chlorination, including milling and calcining, is 15*s.* per ton, but it is expected that, with the introduction of a number of revolving furnaces and facilities for the automatic handling of the material, the cost will be reduced to 12*s.* per ton. At the Aldershot smelting works, the auriferous pyrites, complex ores, etc., are made up into suitable mixtures for calcining, and the slagged material is afterwards smelted with roasted mattes, oxidized lead ores, and limestone in a large blast-furnace to a rich auriferous silver lead. The cyanide process in Queensland is necessarily confined to the treatment of tailings. The average extraction from 5 dwt. to 10 dwt. stuff is 70 per cent. to 80 per

[1] The original is in the Library Inst. C.E.

cent., and the average cost of the treatment is 7*s.* 6*d.* to 10*s.* per ton.

The satisfactory nature of gold-mining in Queensland is shown by the official statistics. In 1894 the yield of alluvial gold was 25,938 ozs., and that of gold from quartz mines 653,573 ozs., the total being 679,511 ozs. The number of tons of auriferous quartz crushed amounted to 539,886, yielding on an average 1 oz. 4 dwt. 5 gr. per ton.

B. H. B.

On the Function of Aluminium in the Composition of Glass. By LEON APPERT.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxii., 1896, p. 672.)

The presence of aluminium in glass prevents or retards devitrification, and enables a certain proportion of the soda or potash to be replaced by lime, rendering the glass stronger, more durable and more elastic. It can also with advantage replace 7 per cent. or 8 per cent. of the silica, producing a material slightly more fusible.

Unfortunately, owing to its action upon the oxide of iron, the presence of alumina tends to increase the depth of colour of the glass.

G. J. B.

On the Structure and Constitution of the Alloys of Copper and Zinc. By GEORGES CHARPY.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxii., 1896, p. 670.)

The Author's researches lead to the following conclusions:— Alloys containing from 0 to 35 per cent. of zinc are similar in microscopic structure, the cast metal consisting of an agglomeration of dendridic needles with ramifications at right angles. The dimensions of the crystals vary according to the rate of cooling. Metal kept for a long time at a temperature near the melting point is found to consist of a mass of octahedral crystals with many contact-twins.

Alloys containing a higher percentage of zinc show a quite different structure. The crystals have no dendridic ramifications, but are arranged in groups with rounded outlines imbedded in a magma. With more than 45 per cent. of zinc these groups assume the form of flat polygonal plates, and with 67 per cent. of zinc the metal appears homogeneous, breaking with a conchoidal fracture. In the first class (alloys with from 0 to 37 per cent. of zinc) the impurities, such as lead or tin, collect in the interspaces between the crystals, constituting a solder which is strong while cold, but easily gives way at temperatures above 200° C. But in the second

class, in which the proportion of zinc amounts to 40 per cent. or more, this effect is not produced, and the metal is malleable while hot. The Author considers that these alloys contain two definite compounds, namely, Cu_2 Zn and Cu Zn, in varying proportions, together with free copper or free zinc, according to the percentage-composition of the metal.

G. J. B.

Chinese Ironclads built in Germany. By M. A. Haack.

(Verhandlungen des Vereins zur Beförderung des Gewerbfleisses, 1896, p. 53.)

This Paper contains an account of five Chinese ironclads which had been built at the Vulkan Works, Stettin, Germany, and an account of their performances during the recent Chino-Japanese war.

The Paper is accompanied by five large folding sheets of drawings illustrating the construction of the "Isi Yuen," "King Yuen," and "Li Yuen," and a number of reproductions from photographs, many of which show the damage sustained during the recent actions.

A. S.

Contract Trial of the United States Coast-line Battleship "Indiana." By Harry Hall, U.S. Navy.

(Journal of the American Society of Naval Engineers, November, 1895, p. 637.)

The "Indiana" was built by Messrs. Cramp & Sons, of Philadelphia, from designs furnished by the Navy Department, at a cost of £612,666.

The principal dimensions are as follows:—

Length on W.L.	348 feet.
Beam	69 feet 3 inches.
Draught	24 feet.
Displacement	10,225 tons.
Coefficient of fineness	0·622

There is an armoured belt of Harveyized nickel steel extending from 3 feet above the water to 4 feet 6 inches below the water amidships, and to 4 feet 2½ inches below at the ends. It is 18 inches thick from the top of the belt to a depth of 1 foot below the water, from which point it tapers to 8 inches. The extremities of the belt are connected by an athwartship belt of 14 inches. Above the main belt the sides are protected up to the height of the main deck with 5-inch armour. The armoured deck is 2¾ inches thick over the citadel, and 3 inches at the ends. 17 inches of nickel steel protects the big guns, the smaller gun-

turret being 6 inches. All the guns have armoured protection of a thickness depending upon the importance of the gun. The main battery consists of four 13-inch breech-loading guns mounted in pairs in the two main turrets, eight 8-inch breech-loaders in pairs in four turrets on the superstructure, and four 6-inch breech-loaders, two on each side, on the main deck within the superstructure. The secondary battery consists of twenty 6-pounder Hotchkiss guns, six 1-pounders, and four light guns. All the turrets are worked by steam, and the large guns by hydraulic power. There are six torpedo-tubes.

There are two sets of triple-expansion engines, driving twin screws. The air-pumps are of the Blake single-acting independent type. The propellers are of manganese bronze, with three blades, and have a diameter of 15 feet 6 inches, a pitch of 16 feet, and a developed area of 54 square feet. Steam is supplied by four double-ended main and two single-ended auxiliary boilers of marine type. The total heating-surface amounts to 19,195 square feet, and the grate surface to 616 square feet. The stokeholds are closed and supplied with air by ten fans. On the official trial in October, 1895, a mean speed of 15·5 knots was obtained, at the load draught of water. The steam pressure was 166 lbs., the revolutions per minute 131, and the collective power of the main engines was 9,500 HP., and the total power developed, including auxiliaries, was 9,740 HP. The coal consumption, as measured on a six hours' trial, was 2·02 lbs. per I.HP. per hour.

S. W. B.

New Properties of the Radiations emitted by some phosphorescent Bodies. By HENRI BECQUEREL.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxii., 1896, p. 559.)

The double sulphate of uranyl and potassium, after exposure to light, emits invisible radiations capable of passing through certain substances opaque to light, such as black paper, aluminium, and copper, and affecting a photographic plate in the same manner as the Röntgen rays. It retains this property for several days after being kept in darkness, although the visible fluorescence ceases in about the one-hundredth part of a second after the light has been withdrawn.

The electroscope of Hurmuzescu, which will remain charged for a month if protected from ultra violet rays by yellow glass, was discharged in about three hours by the radiation from a layer of the uranium salt acting through a sheet of aluminium 0·12 millimetre thick, and in from twenty to twenty-five minutes when the phosphorescent material was placed inside the case of the instrument. The Author demonstrated the reflection of the radiations by the following experiment. A piece of the double

sulphate of uranyl and potassium was placed over a sensitized plate and half covered by a polished steel mirror. On development, after fifty-five hours of exposure, the uncovered part gave a sharp image, while the portion under the mirror gave a diffused shadow —as if a second layer of the active substance had been placed a short distance above the first. Slight indications of refraction were obtained by experiments with a glass prism.

Other compounds of uranium, in thin crystalline crusts, were found to possess similar properties; but a highly phosphorescent specimen of artificial hexagonal blende gave negative results, as did also the sulphide of strontium. Sulphide of calcium, showing a blue phosphorescence, was found to produce an image; but a sample giving a green phosphorescence proved inactive. There were signs that the radiation from these substances had been refracted and reflected in passing through the glass tubes in which they were contained.

G. J. B.

Electrical Effect of the Röntgen Rays. By AUGUSTE RIGHI.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxii., 1896, p. 601.)

The Author has investigated the action of the X rays upon charged conductors and dielectrics. Amongst other experiments, he describes the following method of producing results analogous to the well-known figures of Lichtenberg. Underneath the Crookes tube is placed a piece of black paper and a thin sheet of aluminium in connection with the earth so as to intercept all ordinary light. The kathode is connected with one side of an air-condenser, from the other plate, of which a wire leads to a coating of tin-foil on the back of a sheet of ebonite, placed a short distance below the aluminium screen. The experimenter places his hand upon the bare surface of the ebonite, and an exposure of several minutes is given. A mixture of sulphur and red-lead is then dusted over the ebonite in the usual way and a shadow-picture of the hand appears showing the bones. A mixture of powdered talc and manganese dioxide gave still better results.

G. J. B.

On the Invisible Rays emitted by the Salts of Uranium. By HENRI BECQUEREL.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxii., 1896, p. 689.)

Continuing his researches, the Author finds that the rate of discharge of the electroscope under the action of the X rays, as measured by the diminution of the angle of divergence of the gold leaves, is approximately proportional to the intensity of the

radiation. Comparing in this way the action of the double sulphate of uranyl and potassium with that of a Crookes tube, he found that the latter was much more powerful, the ratio being as 22·5 to 2,571·4. The interposition of a plate of quartz 5 millimetres thick reduced these figures to 163·6 in the case of the Crookes tube, and 5·4 with the uranium salt. The effect is therefore proportionally less in the latter case than in the former, and may indicate a difference in the character of the rays emitted.

A film of the uranium salt, which had been kept eleven days in darkness, gave a rate of discharge of 20·69, and the same film, immediately after exposure to the magnesium light, gave 23·08. This remarkable persistence of the invisible radiations made it difficult to measure the effect of various kinds of light in exciting them.

Uranous salts, although neither phosphorescent nor fluorescent, are as active as uranic salts in affecting photographic plates.

A remarkable fact, for which at present no explanation is given, is that whereas the salts of uranium can always be excited by light, the phosphorescent sulphides of calcium and of zinc appear to lose this property, the identical specimens with which photographs had been obtained remaining perfectly inert, even after exposure to the strongest light. Mr. Troost, who had observed the same phenomenon, was making further experiments on the subject.

G. J. B.

Black Light. By Gustave Le Bon.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxii., 1896, p. 188.)

The Author states that a sensitized plate in contact with a photographic negative, placed in a printing frame and covered over with a piece of sheet iron, gave on development after three hours exposure to the light of a paraffin lamp a faint but distinct image of the negative. By placing behind the glass a piece of sheet lead, bent round so as to touch the iron plate, thus enclosing the whole in a metallic case, a much more vigorous image was obtained. Direct sunlight gave similar results, but the effect was not much greater than that of the lamp. Cardboard and metals were easily traversed by the light. Placing the iron plate in front of the sensitive plate in an ordinary camera, he obtained, after two hours' exposure to sunlight, a complete blackening of the film without any visible image save in a few cases. He had not been able to determine the cause of this phenomenon.

G. J. B.

The Packing of Salt in the Tropics. By K. von Balzberg.

(Berg- und Hüttenmännisches Jahrbuch der k. k. Bergakademien, 1895, p. 267.)

In 1891 the Government of the Dutch Indies offered a prize of 10,000 florins for the best suggestion regarding the packing of salt in Java. The Government salt is obtained from numerous salt-pans in the districts of Sampang, Pomekasan and Somenep, in the islands of the same name. After the product has been extracted from the salt-pans and dried for some time by the heat of the sun, it is brought to the Government packing-sheds and stored there for at least a year. During that time most of its hygroscopic constituents are lost, and it is then shipped to the various points of consumption. The salt is of a pale grey colour and still very hygroscopic, so that when exposed to the action of the atmosphere it tends to absorb water and to deliquesce. The specification of the conditions of the prize, therefore, laid down that the packing must completely protect the salt from the action of moisture for at least two years, and must not introduce any impurities. The boxes, or cases, for the salt must hold exactly 1 kilogram, and they must further be packed in large crates for convenience of transport. In addition to the boxes holding 1 kilogram of salt, provision might also be made, if conducive to economy, for packing large quantities in boxes of 5 kilograms, 10 kilograms and 25 kilograms. For the Government salt production, it might be assumed that 74,150,000 boxes of 1 kilogram would be required annually, or in the event of larger boxes being desirable, 37,000,000 boxes of 1 kilogram, 2,470,000 boxes of 5 kilograms, 1,230,000 boxes of 10 kilograms and 500,000 boxes of 25 kilograms. The boxes must be filled as rapidly and as cheaply as possible, preferably by mechanical means. Experience having shown that salt which has been submitted to a drying process keeps better, it would be necessary to devise a suitable method of artificially drying the salt before packing. The total cost, including that of the packing itself, the labour of filling into boxes and the preliminary drying, must not exceed 3 cents per kilogram, calculated on an annual output of 74,150,000 kilograms.

Translations of the judgments of the Dutch Commission at the Hague and of the Indian Commission are appended to the Author's Paper. From these it is seen that the competitors included 148 from Europe, 35 from America, 23 from Asia, 2 from Australia and 1 from Africa. The replies of these 209 competitors are submitted to an exhaustive criticism and the results tabulated.

The Author, who is the Director of the Ischl saltworks, was induced to compete by the fact that he was at the time engaged on a thorough investigation of the question of compressing salt into briquettes for the Austrian works, and he was led to a conclusion that compression into briquettes might be recommended as the best method of packing. As, however, the specification refers only to boxes, moulding the salt would seem *à priori* to be

out of the question. He therefore recommended, as an alternative, packing in the waterproof cardboard made by Karl Lenz, of Vienna, painted over with asphalt varnish, this material being well adapted for packing either loose salt or briquettes. For drying the salt a centrifugal process was advocated. Great difficulty was presented by the fact that the salt might not be weighed, but had to be divided into portions of 1 kilogram, 5 kilograms, 10 kilograms and 25 kilograms. For this purpose an ordinary volumetric division was insufficient; and the Author therefore submitted designs for an apparatus which took into account the unequal density of the salt. The enormous output of 74,150,000 kilograms of salt rendered it necessary to design three independent establishments, full details of which are given. The total packing cost, based on this annual output, is 2·4 cents.

The alternative solution to the problem suggested by the Author is the preparation of salt briquettes with the aid of a hydraulic press working up to 200 atmospheres. By this pressure the salt is reduced to half the volume of the loose salt, so that great advantages in storing and shipping are presented. If wet salt is treated the briquette of salt loses most of its hygroscopic properties. A press designed by P. Mayer, of Vienna, for the purpose is described and illustrated. The freshly-pressed briquettes have a considerable tensile strength, so that they may be transported in waterproof paper without further drying. They may, however, as they contain only 6 per cent. to 7 per cent. of moisture, acquire very great tensile strength by a brief drying process. With a press working very slowly a briquette can be made in ten seconds, so that to turn out 103,933 briquettes of 1 kilogram daily fifteen briquette-machines would be required, and for 6,939 briquettes of 5 kilograms, 3,455 briquettes of 10 kilograms and 1,405 briquettes of 25 kilograms, one press would be required in each case. If the whole of the salt output were made into 1-kilogram briquettes twenty-seven presses would be required. In the latter case the cost would be 0·882 cent for 1 kilogram of compressed salt.

In the reports of the Dutch and Indian Commissions, appended to the Author's Paper, it is stated that of all the replies received his was the best solution to the problem, and that there could be no doubt that the prize offered by the Dutch-Indian Government should be awarded to him.

B. H. B.

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1895–96.—Part III.

N.B.—Titles in italics refer to Original Papers, and those selected for printing only are further distinguished by the suffix "(S.)" or "(St.)," the latter denoting Students' Papers. Abstracted Papers are not so indicated.

LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
STAMFORD STREET AND CHARING CROSS.

LIT

PLATE 1.

Fig: 6.

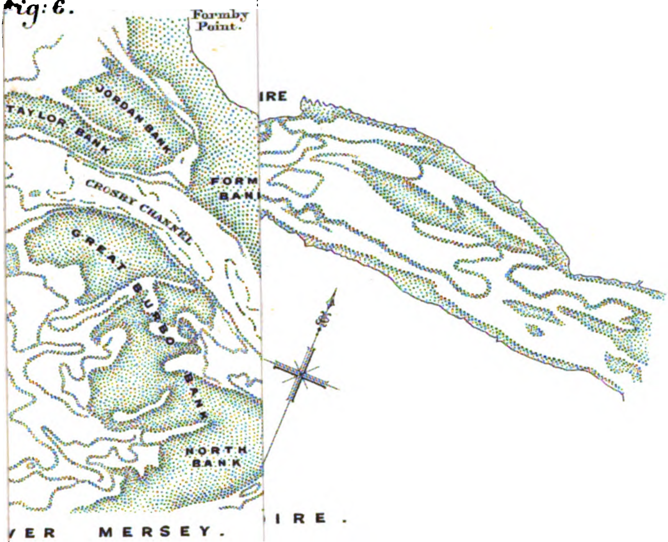
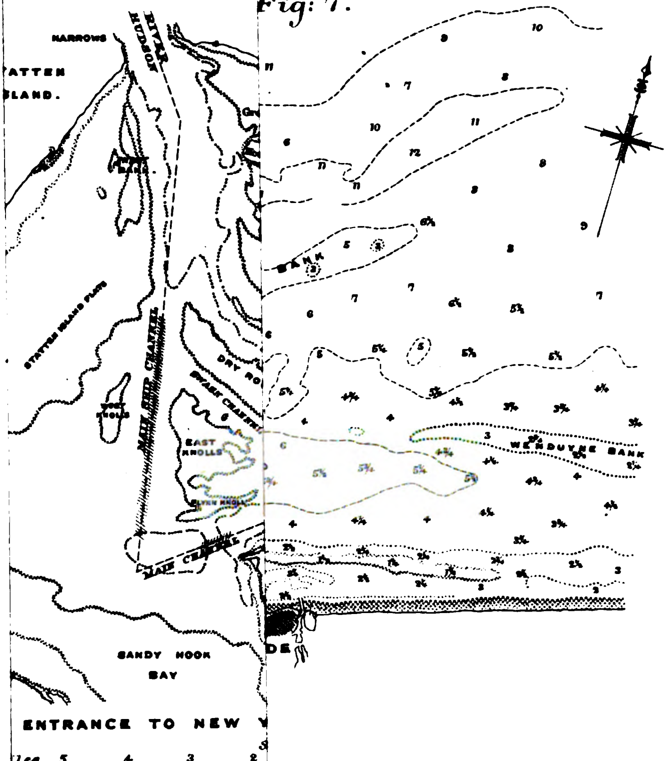
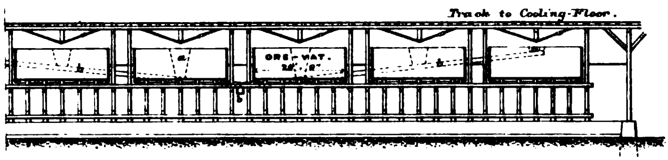


Fig: 7.



f Proceedings of The Instit

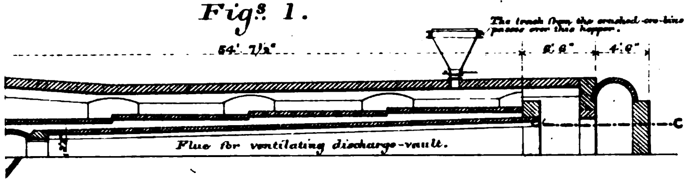
THOS KELL & SON, LITH.



SECTION AT B B.

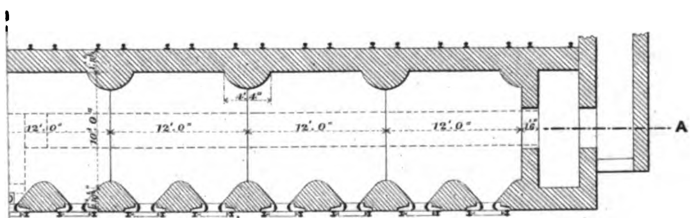
For Figs 2.
0 50 Feet.

Figs 1.

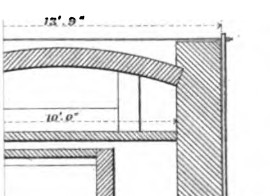


SECTION AT A A.

Scale for Figs 1.
Feet 10 5 0 10 20 30 Feet.

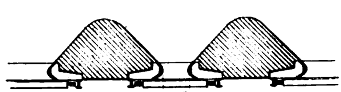


PLAN AT C C.



D SECTION AT B B.

Scale.
1 0 5 Feet.



ENLARGED SECTION OF DOOR.

THOS KELL & SON, LITH.

PLATE 5.

Fig

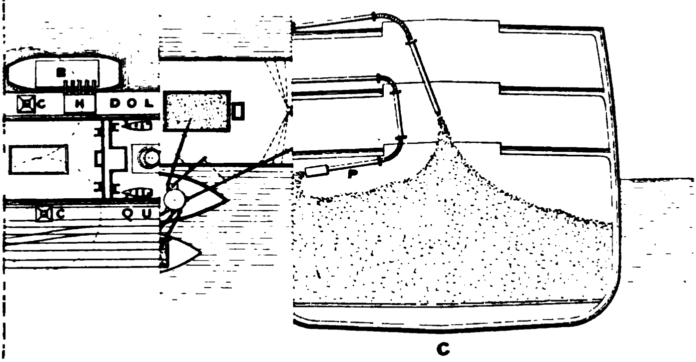
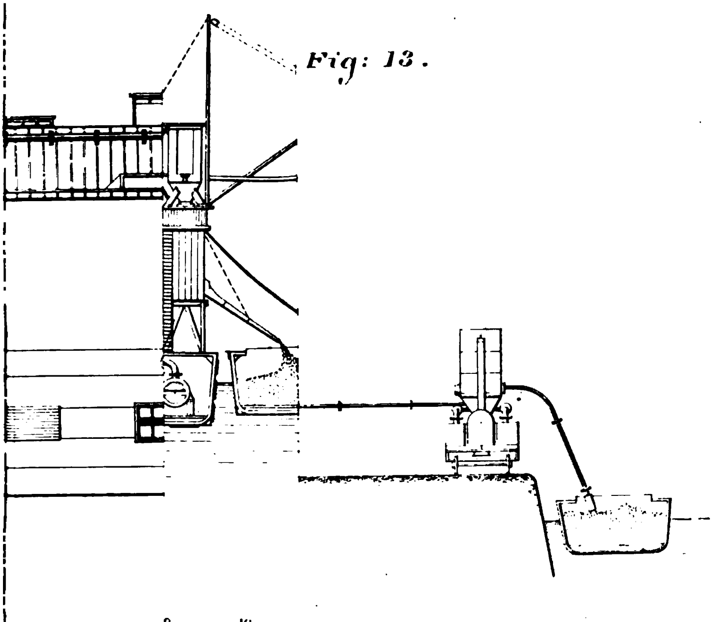


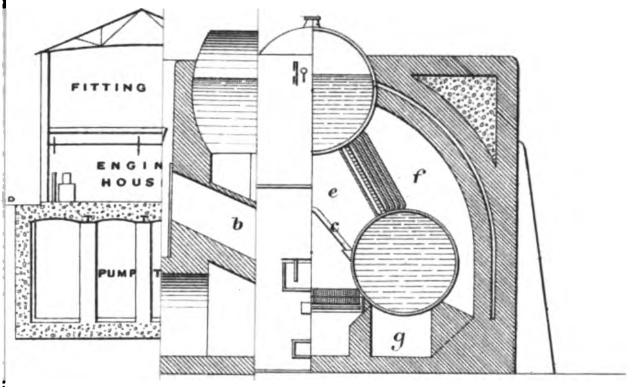
Fig: 13.



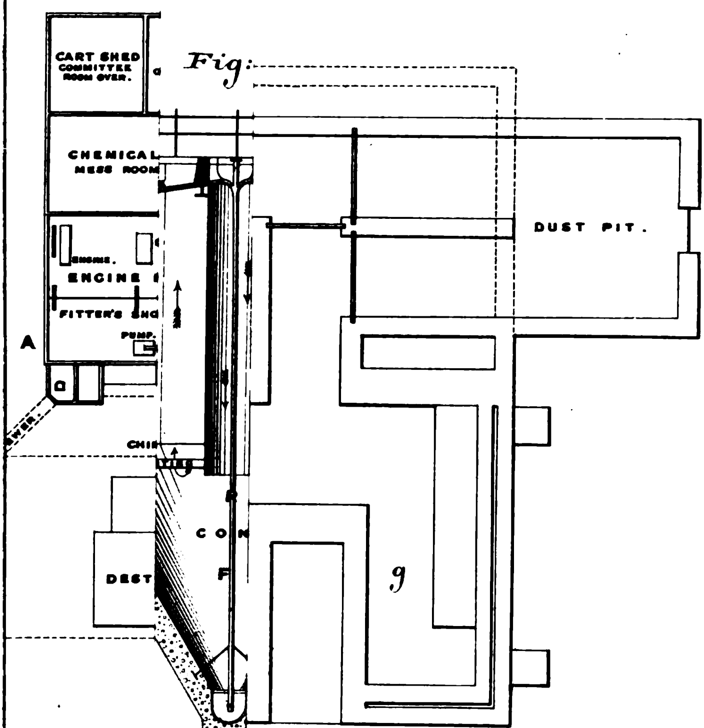
t III.

THOs KELL... LITH. LONDON.

PLATE 6.



NAL SEC ELEVATION.



PLAN.

ON LINE
RTMUN

THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.